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Effect of Yarn Physical Properties on Fiber Migration and Packing Density of Cotton/Acrylic Blended Yarns

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ABSTRACT

In the scope of the study, the effect of fiber blending ratio, yarn count and twist factor on fiber migration, packing density and diameter of the cotton/acrylic blended yarns were investigated. The yarn samples with 75/25%, 50/50%, 40/60% cotton/acrylic blending ratios were produced with three different yarn numbers; 20/1 Ne, 24/1 Ne, 30/1 Ne and three twist factors; 3.5 αe, 4 αe, 4.5 αe. Thus, totally 27 yarn samples were obtained. The yarn cross-sectional samples were sliced with microtome. The image frames of yarn cross-sections were acquired via digital microscope. The yarn packing density was calculated by using image processing algorithm and the fiber migration was determined via cross-section images. The results were evaluated statistically. When the results of the study were examined, it was seen that the yarn blend ratio, twist factor and yarn count have a significant effect on the yarn packing density and diameter properties. According to fiber migration analyze results, it was revealed that the acrylic fiber distributed toward the yarn surface with (+) sign index values and cotton fiber distributed to core of the yarn with (-) sign index values for all yarn counts and twist factors of 40/60 and 50/50 cotton/acrylic blend ratios.

KEYWORDS

Fiber migration, yarn packing density, yarn diameter, blended yarn, image processing

1. INTRODUCTION

The blended yarns are produced by combining two or more different fiber components in order to benefit their advantages and strength in the same final product. Since synthetic and natural fibers have different mechanical, chemical and comfort characteristics, they are blended within the same yarn structure according to the required yarn properties. The distribution and uniformity of the fibers in the blended yarns cross-sections are important for determining the structural, functional, mechanical and visual properties of the products. The outer fibers tend to show more tension as they travel a longer distance during the ring yarn production. However, the fibers in the yarn center have a lower tension because they follow a straighter path. The outer fibers try to move to the inner region because they tend to have low density, while the inner fibers tend to have the opposite direction. The tendency of the fibers to displace during yarn formation is called fiber migration. In other words, variations of the fiber placement in the yarn can be defined as fiber migration. The two most important parameters to be considered in terms of cohesion and rigidity are yarn twist and fiber migration [1-8]. The packing density that is the maximum amount of fiber in yarn cross-section is also very significant parameter because it determines the characteristics of the yarn such as feeling, dyeing, thermal conductivity and bulkiness. [5]. Properties of the fibers such as elasticity, rigidity, length, fineness and strength have considerable influence on yarn properties. The rigidity and cohesion properties of the fibers are significant in the spinning and twisting process. It has been stated that as the twist factor becomes higher, yarns will have a stiffer structure because of holding fibers more tightly. It has been mentioned that the covering ability is reduced due to the decrease in the yarn diameter [9-14].

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The relationship between yarn structure and yarn properties has been investigated with many different previous studies. In the literature it was stated that the yarn hairiness has major effect on packing density of a yarn. The increase in hairiness leads to the increase in inter-fiber distance. As the hairiness increases, yarn diameter also increases which decreases the packing density of yarn [15, 16]. If the number of twists on the yarn structure is high, it ensures that the fibers are held firmly. Since the pores in fibrous assemblies determines displacement of a fiber-air interface with a fiber-liquid interface in a capillary system, the liquid transfer through the fiber assemblies is restricted with high twist level due to less pores between fibers. So, high twisted yarns are often preferred where good water resistance and less is desired. The twist factor has important effect on yarn diameter and softness. So, it can be stated that the twist factor affects the structural and appearance properties of the yarn. Wearing properties (abrasion and pilling) are improved with the increase in the twist factor. Raising the level of twist helps to endure abrasion since the fibers cannot be easily pulled out of the yarn [15-20]. The fiber intensity incorporated into the yarn structure determines the yarn structural integrity. The higher fiber intensity leads to higher fiber cohesion and increased yarn strength [18].

Most of the previous studies about the effect of yarn physical properties on structural properties have focused on yarn samples with single fiber type [21-30]. Especially, the fiber migration characteristics have been analyzed mostly for single fiber types. Furthermore, the distribution of cotton and acrylic fibers in yarn cross-section have not been investigated yet. Since each fiber component demonstrate different behavior during their individual movements in spinning process, the distribution of the fiber component in yarn cross-section and fiber clustering characteristics changes according to the fiber type. So, this study was conducted to analyze the fiber distribution attribute for different cotton/acrylic blend ratios. The effects of yarn twist factor and linear density on fiber distribution characteristics were also investigated. Thus, the relationship between yarn physical properties (fiber blending ratio, yarn count and twist factor) and fiber distribution attributes (fiber migration, yarn packing density and yarn diameter) was revealed.

2. MATERIAL AND METHOD

2.1 Material

For the purpose of the study, ring spun yarns were produced with 3 different cotton/acrylic blend ratios and 3 different twist factors of each yarn count. The blend ratios were determined as 75/25%, 50/50%, 40/60% cotton/acrylic. Sample yarns were blended as fibers in the blowroom line. The twist factors were determined as α_e=3.5, 4, 4.5 and the yarn counts were chosen as Ne 20/1, 24/1, 30/1. Thus, totally 27 yarn samples were produced by using conventional ring spinning machine (Zinser 351). The fiber properties used in yarn production are submitted in Table 1. The physical properties of yarn samples are given in Table 2.

All yarn samples were tested with Uster Tester 5-S800. The test device adjustment was determined as speed (v) = 5000 mm/min, measurement length (Lh) = 500mm, pre-tension (Fv) = 12.3 cN/tex. The tests were performed on sample coils. For each yarn property, 10 measurement were taken from each sample.

In the scope of the study, production was performed on the machine park shown in Figure 1. Yarns were produced via blowroom blend. The brand of blowroom, card machine, draw frame and regulated draw machine is Trützschler. The roving frame and ring machine brand is Zinser.

Table 1. Fiber properties

Fiber Properties	Cotton (American)	Acrylic (Dralon)
Fiber Fineness (dtex)	2.05	1.3 ± 0.2
Fiber Length (mm)	28.72	37
Strength	30.6 g/tex	26 cN/tex
Breaking Elongation (%)	5.10	23 ± 5 %
U.I.	81.8	-
SFI	8.4	2.4
CG	30-1	898
Reflectance	76.6	Bright
Moisture (%)	6.6	-

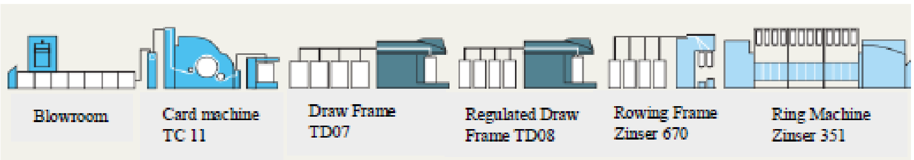


Figure 1. Ring spinning production line

Table 2. Yarn physical properties

	Blend Ratio % (Cotton/ Acrylic)	Ne	Twist Factor, α_e	U%	CVm %	Thin -50%	Thick +50%	Neps +200%	H.	Strng. (cN/tex)	Elong. (%)
1	**40/60**	**30/1**	**3.5** α_e	11.99	15.53	16.30	268.80	580.00	8.86	13.18	8.80
2	**40/60**	**30/1**	**4.0** α_e	12.13	15.59	11.30	303.80	665.00	7.86	12.59	7.31
3	**40/60**	**30/1**	**4.5** α_e	11.96	15.33	10.00	245.00	617.50	7.02	13.86	7.74
4	**40/60**	**24/1**	**3.5** α_e	10.99	14.08	1.30	176.30	246.30	9.19	13.69	8.62
5	**40/60**	**24/1**	**4.0** α_e	10.50	13.45	1.30	120.00	227.50	8.36	13.70	8.62
6	**40/60**	**24/1**	**4.5** α_e	10.91	13.95	1.30	121.30	232.50	10.62	12.38	8.98
7	**40/60**	**20/1**	**3.5** α_e	9.86	12.57	0.00	58.80	168.80	9.58	14.62	9.31
8	**40/60**	**20/1**	**4.0** α_e	9.72	12.47	0.00	78.80	206.30	8.48	14.50	9.00
9	**40/60**	**20/1**	**4.5** α_e	9.92	12.67	2.50	91.30	211.30	10.74	13.10	9.70
10	**50/50**	**30/1**	**3.5** α_e	11.20	14.35	2.50	168.80	372.50	8.29	5.77	13.32
11	**50/50**	**30/1**	**4.0** α_e	11.07	14.12	2.50	146.30	385.00	7.19	13.45	6.85
12	**50/50**	**30/1**	**4.5** α_e	12.01	15.40	8.80	278.80	518.80	6.66	13.69	7.29
13	**50/50**	**24/1**	**3.5** α_e	10.14	12.92	1.30	88.80	202.50	7.30	13.90	7.55
14	**50/50**	**24/1**	**4.0** α_e	9.90	12.67	0.00	95.00	142.50	8.29	13.39	7.47
15	**50/50**	**24/1**	**4.5** α_e	10.05	12.82	0.00	100.00	148.80	10.35	13.16	7.62
16	**50/50**	**20/1**	**3.5** α_e	9.40	12.00	0.00	38.80	135.00	9.64	13.63	7.70
17	**50/50**	**20/1**	**4.0** α_e	9.29	11.83	0.00	47.50	132.50	8.14	14.88	8.17
18	**50/50**	**20/1**	**4.5** α_e	9.14	11.65	0.00	46.30	168.80	7.74	15.84	8.95
19	**75/25**	**30/1**	**3.5** α_e	13.12	17.03	12.50	475.00	738.80	8.95	9.99	5.68
20	**75/25**	**30/1**	**4.0** α_e	13.52	17.41	11.30	470.00	792.50	8.13	13.30	6.50
21	**75/25**	**30/1**	**4.5** α_e	13.42	17.31	23.80	515.00	833.80	7.18	14.03	6.28
22	**75/25**	**24/1**	**3.5** α_e	12.21	15.64	2.50	258.80	283.80	9.19	12.35	5.93
23	**75/25**	**24/1**	**4.0** α_e	11.74	15.15	1.30	260.00	262.50	8.91	13.40	6.27
24	**75/25**	**24/1**	**4.5** α_e	12.05	15.48	2.50	271.30	246.30	7.90	14.97	6.58
25	**75/25**	**20/1**	**3.5** α_e	11.61	14.83	0.00	157.50	165.00	10.56	11.58	6.10
26	**75/25**	**20/1**	**4.0** α_e	10.65	13.63	0.00	96.30	142.50	9.16	14.66	7.30
27	**75/25**	**20/1**	**4.5** α_e	11.22	14.39	0.00	160.00	203.80	7.83	15.60	7.64

2.2 Method

2.2.1. Fiber Migration

The distribution of fibers in the yarn cross-section has significant effect on yarn physical and performance properties. In order to determine the visual, mechanical and structural properties of the blended yarns, the fiber distribution and the fiber blend irregularity in the cross-section are evaluated as vital parameters. Mathematical models were proposed to analyze the radial pattern in packing density [31] and fiber distribution irregularity [27]. Most common method used for the fiber distribution analysis for blended yarns is Hamilton Fiber Migration Index [27]. *Hamilton Migration Method (HMM)* analyzes the fiber distribution and orientation in yarn cross-section and explains it as an index. This index is predicated on the specific first moments of the fibers around the center of the yarn cross-section. The migration index is attributed to specific first moments of a constituent about the center of yarn cross-section and relates the moment (*FMa*) corresponding to the actual distribution of moments that are three hypothetical distributions; uniform distribution ($FM\,\mu$), maximum inward migration *(FMI)* and maximum outward migration ($FM\ o$) respectively. Therefore, it can be said that the fiber migration index is an explanation of whether the migration is outward or inward.

In accordance with HMM, first of all, the digital image of yarn cross-section is divided into 5 equal parts as shown in Figure 2. The different fibers in the mixture are identified by a separate letter. In this study, **"a"** was used for acrylic and **"c"** was used for cotton [8].

a_i *: Acrylic fibers quantity*

c_i *: Cotton fibers quantity*

i : Sectional ring number

For all rings, the quantity of the fibers in the mixture are counted separately [8].

Because the densities of the acrylic and cotton fibers are different, the fiber cross-section areas are not the same with the same linear densities [8]. So, the ratio of fiber numbers for each layer is converted into ratio of the fiber volume by means of Equation (1):

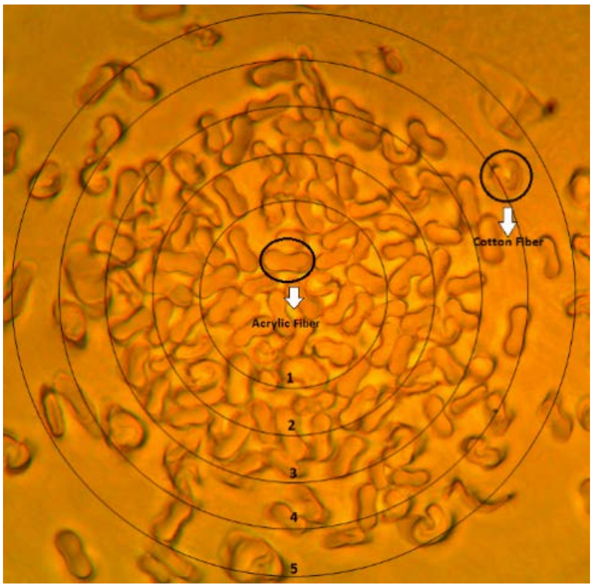


Figure 2. Dividing the yarn cross-section into 5 equal areas

$$C = \frac{\mathbf{VA}}{\mathbf{VC}} = \frac{\mathbf{TA}\,.\rho_C}{\mathbf{TC}\,.\rho_A} \quad (1)$$

Where;

V_A = the volume of acrylic fibers,
V_C = the volume of cotton fibers,
T_A = the linear density of the acrylic fiber (dtex)
T_C =the linear density of the cotton fiber (dtex)
ρ_A = the density of the acrylic fiber (g/cm^3),
ρ_C = the density of the cotton fiber (g/cm^3),
C = ratio between the volume of the acrylic fibers and cotton fibers.

The relative volume of the acrylic fibers, $a_i^{'}$, is calculated by multiplying the number of acrylic fiber (a_i) with coefficient C. Similarly, the relative volume of cotton fibers, $c_i^{'}$, is determined by multiplying the number of cotton fibers (c_i) with coefficient C. The relative volume of fibers at each layer, $t_i^{'}$, is the sum of $a_i^{'}$ and $c_i^{'}$.
The actual moment (FM_a) and uniform moment (FM_u) of acrylic fiber distribution in the yarn cross section is calculated with Equation (2) and Equation (3) respectively.

$$FMa = (-2a'_1) + (-1a'_2) + (0a'_3) + (1a'_4) + (2a'_5) \quad (2)$$

$$FMu = \frac{A}{T[2(t'_5 - t'_1) + (t'_4 - t'_2)]} \quad (3)$$

Where, $A = \sum a'_i$, $T = \sum t'_i$.

If $FM_a < FM_u$, the acrylic fibers are prior to transfer inward. Then the fiber migration index (M_{in}) is calculated with following Equation (4).

$$M_{in} = \frac{FM_a - FM_u}{FM_u - FM_i} \times 100\% \quad (4)$$

If $FM_a > FM_u$, the acrylic fibers are prior to transfer outward. The fiber migration index (M_{out}) is calculated with following Equation (5).

$$M_{out} = \frac{FM_a - FM_u}{FM_o - FM_u} \times 100\% \quad (5)$$

Where;

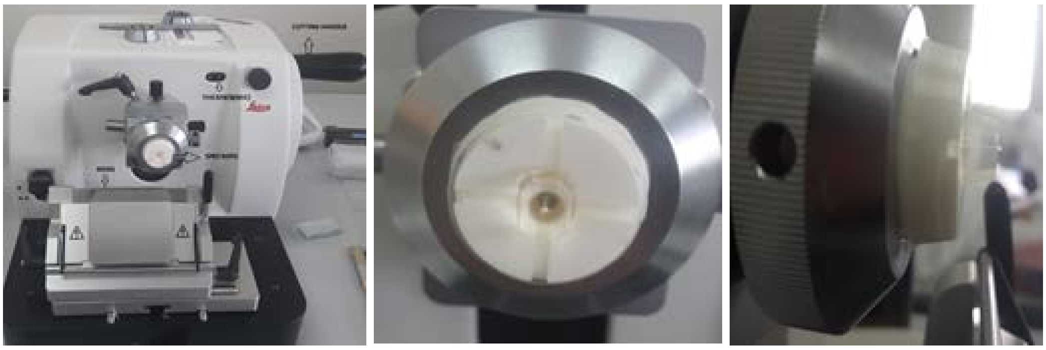
FM_o is the maximum possible outward migration of the component and FM_i is the maximum possible inward migration.

The fiber migration index (M) has values between -100% and +100%. When the fiber migration index (M) takes a negative sign, it indicates that the fiber component migrates to inner layer. On the other hand, the positive sign of the fiber migration index value indicates that the fiber component migrates to the outer layer [27]. When the fiber migration index value is zero, it can be said that the fibers are uniformly distributed within the yarn cross-section. In this case, uniform and balanced distribution of fiber components on the core and the surface is obtained [6].

In order to analyze the fiber migration index, the cross-section views of the yarn samples were taken under microscope. For this aim, the yarn cross-section slices were obtained with microtome device (Figure 3). Each yarn sample was inserted through a special mold and fixed by using solidification resin. The yarn molds were placed into a mold holder to fix them on the microtome device. For each sample, 10 slices were taken via microtome with an optimum section thickness value of 16µm. An image processing system that consists of digital microscope camera, computer and image processing software was constructed as given in Figure 4. After the slices were taken at the specified thickness, they were analyzed under a microscope and yarn cross-section image frames were acquired. The migration rings (Figure 2) were inserted precisely on the yarn cross-section image frame by using MATLAB Image processing toolbox and the fibers were counted manually in each ring.

2.2.2. Yarn Diameter

In this study, yarn diameter was measured by using Uster Tester 5-S800. The Uster Tester 5 is a modular laboratory system, which measures the yarn diameter, density and roundness with optical sensor. The system also determines yarn evenness based on 0.3 mm and 8 mm measuring zone. Short-term diameter variations were measured with 0.3 mm zones. The Uster Tester 5 uses two parallel light beams creating double illumination on the yarn to measure these parameters optically in a two-dimensional environment at a high degree of sensitivity and precision [32].



(a) (b) (c)

Figure 3. Microtome and yarn sample mold views; (a) Microtome (b) yarn sample mold front view (c) yarn sample mold side view

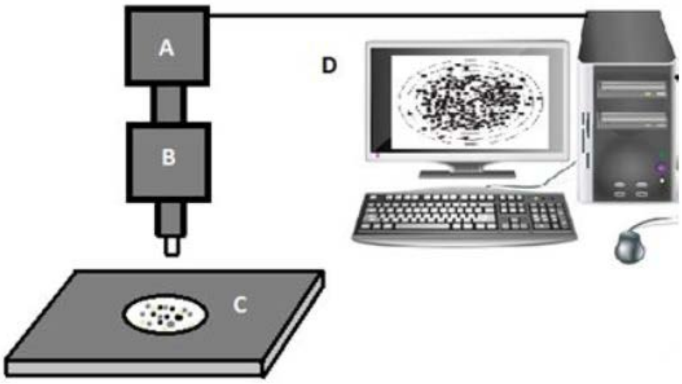


Figure 4. Schematic diagram of the image-processing system (A) Camera (Leica DM1000), (B) Optical microscope, (C) Yarn cross-section sample, (D) Computer

2.2.3. Yarn Packing Density

Packing density is accepted as an important feature for yarn structure because it has a significant effect on many properties such as yarn feel, thermal conductivity, bulkiness, dyeability etc. Besides this, it has been seen that the amount of maximum yarn that can be wound on a package is also affected [15]. Packing density was calculated by the ratio of total area of fibres in a given zone to the total area of zone in the yarn cross-section. The yarn packing density can be determined by using three different methods; direct method, secant method and tracer fiber method. In this study, direct method was used.

The yarn packing density was determined by using image processing method that has also been proposed by Kılıç M. et al. [25]. For this aim, the cross-section image frames of the yarn samples acquired by using the system in Figure 4 were also used for yarn packing density analysis. Cross-sectional images were processed with the algorithm that is prepared in MATLAB environment. The flow chart of the developed image processing algorithm was given in Figure 5. In yarn cross-section view, the space between fibers was detected in accordance with the light intensity differences between fibers and spaces.

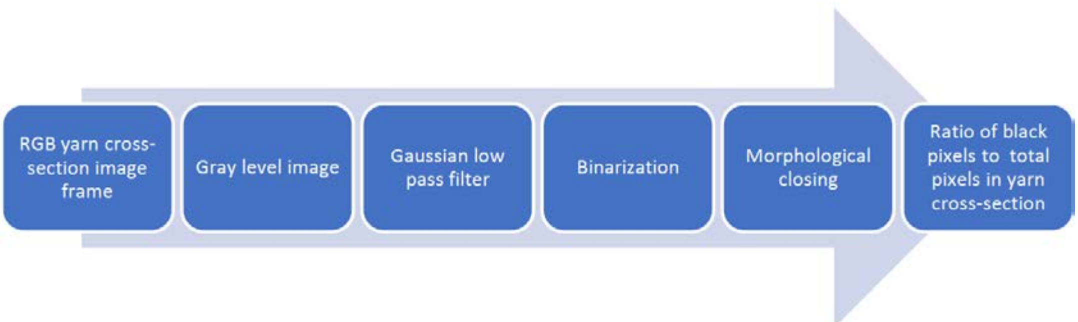


Figure 5. Yarn packing density algorithm

The size adjustments were made on the yarn cross-section image frames. The image frame in RGB (Figure 6.a) form was converted to gray level. The noise removing operation was achieved by using Gaussian filter. The Gaussian filter was used for image smoothing as low-pass filter. Then, the image frame was converted to binary form (Figure 6.b) via Otsu's thresholding technique. In order to determine the yarn packing density exactly, morphological closing was applied to fill in the spaces in fiber lines (Figure 6.c). Closing is the name given to the morphological operation of dilation followed by erosion with the same structuring element. The yarn total cross-section area is calculated by selecting the maximum axis of the binary image size as the diameter of the yarn (Figure 6.c). Finally, the ratio of total black pixels to total pixels in yarn cross-section area was calculated as yarn packing density.

3. RESULT AND DISCUSSION

3.1. Fiber Migration Results

In the yarn samples consist of two different fiber mixture, the migration index takes the same value for each fiber component but in the opposite sign. Therefore, the sum of the migration index of the two fibers is equal to zero. In case of yarns consisting of more than two fibers, calculating the migration index is not as simple as mentioned, but it is calculated in a more complex way [8]. As the number of fiber components increases, since the number of equations will increase, more difficult and complex calculation must be made for each fiber type separately. In accordance with HMM calculation, the migration index of cotton and acrylic fibers were given in Table 3. For each yarn sample, 10 migration index calculation were performed and average migration index value was presented.

The migration index and direction in term of (-) and (+) signs of both acrylic and cotton fibers was presented according to yarn count and twist factor groups in Figure 7(a) and Figure 7(b) respectively. Migration values of acrylic and cotton fiber components are given separately for each sample. The (-) sign in the values (Table 3) indicates that the fiber is oriented towards the yarn core. Migration values with (+) sign (Table 3) indicate that the fiber is oriented towards the yarn surface. When the results were analyzed according to the blend ratio, it can be clearly seen that the acrylic fiber distributed toward the yarn surface with (+) sign index values and cotton fiber distributed to core of the yarn with (-) sign index values for all yarn counts and twist factors of 40/60 and 50/50 cotton/acrylic blend ratios. According to the theoretical and experimental findings, it was proved that the fibers with higher Young's modulus move toward the inner side of the yarn structure. So, the mass percentage of the fibers with lower Young's modulus increases on the external side of the yarn structure [1,5,27]. Since the acrylic fiber have lower Young's modulus than that of cotton, the acrylic fibers located to the surface of the yarn and the cotton placed on the core. This result coincidence with the previous studies submitted by Ryklin D. and Silich T. [1] and Najar S.S. et all. [5]. This situation is different for 75/25 cotton/acrylic blended yarns. The acrylic fiber placed to the core of the yarn and the cotton fiber placed to the outer side of the yarn cross-section for 75/25 cotton/acrylic yarn samples for all counts and twist factors. This result was attributed to the fact that the cotton fiber occupies the larger part of the yarn cross-section and also cotton fiber component have higher length than acrylic fiber (Table 1). When the general trend of acrylic migration index with respect to the cotton blend ratio is investigated, it can be said that as the acrylic ratio increases, the cotton fibers migrate to the core and the acrylic fiber migrates to the outward of the yarn cross section. According to the yarn linear density, as the yarn becomes thicker, the migration indexes of components increase in all mixtures. This obtained result coincides with experimental and theoretical findings of the study achieved by Zheng, S.M. et all. [27]. It was proved that the migration index values are larger with courser yarns [27].

Table 3. Fiber migration index (M) values (%)

Cotton/Acrylic Blend Ratio (%)	Twist Factor (αe)	Yarn Count (Ne)	M (Acrylic)	M (Cotton)
		30/1	7	-7
	3.5	**24/1**	9	-9
		20/1	10	-10
		30/1	8	-8
40/60	**4**	**24/1**	10	-10
		20/1	8	-8
		30/1	10	-10
	4.5	**24/1**	11	-11
		20/1	12	-12
		30/1	4	-4
	3.5	**24/1**	6	-6
		20/1	7	-7
		30/1	6	-6
	4	**24/1**	7	-7
		20/1	9	-9
		30/1	7	-7
50/50	**4.5**	**24/1**	8	-8
		20/1	9	-9
		30/1	-10	10
	3.5	**24/1**	-11	11
		20/1	-12	12
		30/1	-11	11
75/25	**4**	**24/1**	-12	12
		20/1	-14	14
		30/1	-12	12
	4.5	**24/1**	-13	13
		20/1	-14	14

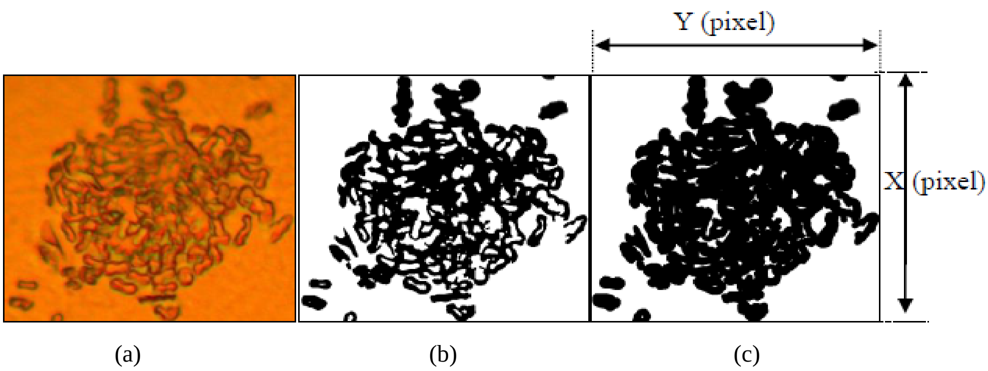
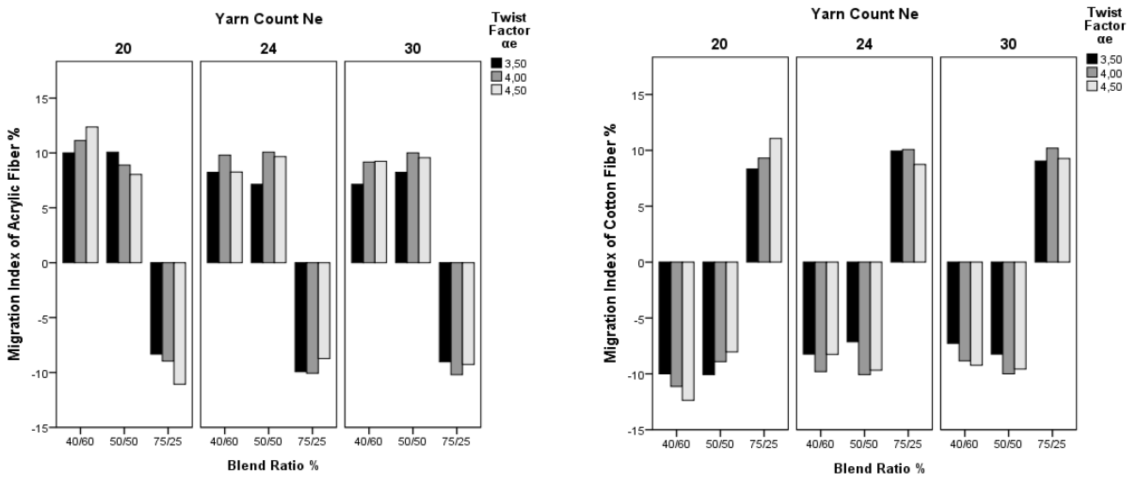


Figure 6. Packing density MATLAB views of yarn cross-sections, (a) Microscope view, (b) Binary view, (c) Closing morphological view



a) Acrylic **b)** Cotton

Figure 7. Fiber Migration Index (%) values representation

Since the migration index values of the both fiber components differ only for their signs, ANOVA is made for only one component in order to determine the significance of the independent components; yarn count, twist factor and blend ratio. In this study, univariate analysis of variance test was used for ANOVA. According to ANOVA results in Table 4, among three yarn physical properties, only the fiber blend ratio has statistically significant (Sig = 0.000) effect at 95% confidence interval on fiber migration values.

Tukey multiple comparison test was applied to compare the acrylic migration values of the blend ratios (Table 5). According to the results of Tukey analysis, it is seen that there is a significant difference between the values 75/25 blend ratio and other two blend ratios of 40/60 and 50/50. However, there is no difference between the acrylic migration values of the yarn samples with 40/60 and 50/50 blend ratios. The lowest acrylic migration value was obtained with 75/25 blend ratio, while the highest acrylic migration value was obtained with 50/50 blend ratio. As observed from the subsets, the acrylic fiber positioned to the core of the yarn cross-section with 75/25 cotton/acrylic blend ratio and they are placed to the outer surface of the yarn structure with 50/50 and 40/60 cotton/acrylic blend ratios.

Table 4. Acrylic fibers migration ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Acrylic Migration**					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Blend Ratio	63566.430	2	31783.215	**862.894**	**.000**	.688
Twist Factor	71.207	2	35.604	.967	.381	.002
Yarn Count	125.267	2	62.633	1.700	.183	.004
Error	28840.467	783	36.833			
Total	100822.000	810				
Corrected Total	93459.822	809				
a. R Squared = .691 (Adjusted R Squared = .681)						

Table 5. Tukey multiple comparison test of blend ratio on acrylic fiber migration

Blend Ratio %, (Cotton/Acrylic)	N	Subset	
		1	2
75/25	270	-9.51	
50/50	270		9.07
40/60	270		9.48

3.2. Yarn Diameter Results

The fibers are considered as the main factor in the yarn structure. More efficient estimation of the fabric properties is achieved by knowing the volume of fibers in the yarn formation. One of the parameters used in the analysis of fabric structural properties such as width, cover and comfort is the yarn diameter. The cover factor of the fabric can cause a large change even with a small change in the diameter of the yarns. As the twist factor increases, the yarn diameter decreases. Similarly, when the yarn count in Ne increases, that means the finer yarns, the yarn diameter decreases [12]. The yarn diameter measurements that were achieved with Uster Tester 5 are given in Table 6.

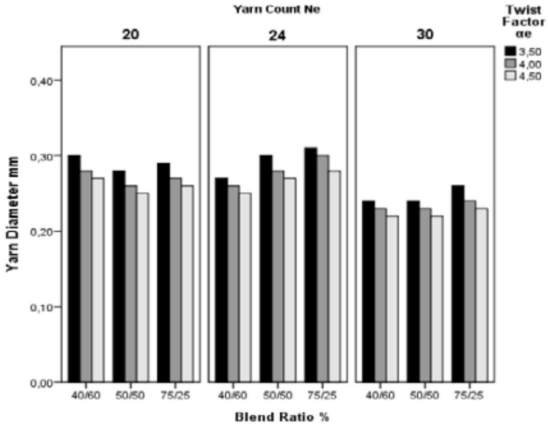


Figure 8. Yarn diameter values

Table 6. Yarn diameter values

	Blend Ratio % (Cotton/Acrylic)	Yarn Count, Ne	Twist Factor, α_e	Diameter (mm)
1	40/60	30/1	3.5	0.24
2	40/60	30/1	4	0.23
3	40/60	30/1	4.5	0.22
4	40/60	24/1	3.5	0.27
5	40/60	24/1	4	0.26
6	40/60	24/1	4.5	0.25
7	40/60	20/1	3.5	0.30
8	40/60	20/1	4	0.28
9	40/60	20/1	4.5	0.27
10	50/50	30/1	3.5	0.24
11	50/50	30/1	4	0.23
12	50/50	30/1	4.5	0.22
13	50/50	24/1	3.5	0.28
14	50/50	24/1	4	0.26
15	50/50	24/1	4.5	0.25
16	50/50	20/1	3.5	0.30
17	50/50	20/1	4	0.28
18	50/50	20/1	4.5	0.27
19	75/25	30/1	3.5	0.26
20	75/25	30/1	4	0.24
21	75/25	30/1	4.5	0.23
22	75/25	24/1	3.5	0.29
23	75/25	24/1	4	0.27
24	75/25	24/1	4.5	0.26
25	75/25	20/1	3.5	0.31
26	75/25	20/1	4	0.30
27	75/25	20/1	4.5	0.28

The diameters of the samples were compared according to the blend ratio, yarn count and twist factor in Figure 8. When the yarn sample diameters were analyzed according to yarn count, it is seen that with 40/60 cotton/acrylic blend ratio, yarn diameter value increases as the yarn gets courser. However, similar consistency was not obtained with other blend ratios;50/50 and 75/25 cotton/acrylic. As observed from Figure 8, the yarn diameter increases from Ne 20/1 to Ne 24/1 and it decreases from Ne 24/1 to Ne 30/1. When all the yarn samples are investigated, it can be observed that the yarn diameter decreases as the twist factor increases in the same blend ratio. For the yarn samples with 24 Ne count, the yarn diameter increases with the increase of cotton fiber content for all twist factor values.

According to the variance analysis of yarn diameter results (Table 7), all yarn physical parameters; yarn count (Sig = 0.000), twist factor (Sig = 0.000) and blend ratio (Sig = 0.000) have significant effect on the yarn diameter results in 95% confidence interval. When F values are examined, it is seen that the highest effect comes from yarn count (F = 185.444). Other two parameters; blend ratio and twist factor have fewer effects on the yarn diameter than yarn count.

Tukey multiple comparison tests were applied to compare the yarn diameter values of the blend ratio, twist factor and yarn count groups. According to the Tukey analysis results for blend ratio (Table 8), it is seen that there is a significant difference between 75/25 blend ratio and other blend ratio groups. However, it is seen that there is no difference between the yarn diameter values of the yarn samples with the blend ratio of 40/60 and 50/50. The lowest yarn diameter values were obtained in the blend ratio of 40/60, while the highest yarn diameter values were obtained in the blend ratio of 75/25. According to Table 8, it can be analyzed that the yarn diameter increases, as the cotton ratio of yarn content increases.

According to Tukey table given in Table 9, there is a significant difference between the yarn diameter values of the yarn samples with the twist factors; α_e = 3.5, α_e = 4 and α_e = 4.5. The lowest yarn diameter value was obtained with α_e = 4.5, and the highest yarn diameter was obtained in α_e =3.5. Also, it is seen that the yarn diameter values decrease as the twist factor increases. This finding can be explained by the fact that the twist effect has a higher radial force and thus results in a more compact and stiffer yarn structure.

Table 7. Yarn diameter ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Diameter**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Blend Ratio	.003	2	.002	17.444	**.000**	.392
Twist Factor	.011	2	.005	52.778	**.000**	.662
Yarn Count	.037	2	.019	**185.444**	**.000**	.873
Error	.005	54	.000			
Total	5.659	81				
Corrected Total	.057	80				
a. R Squared = .906 (Adjusted R Squared = .861)						

Table 8. Tukey multiple comparison test of blend ratio on yarn diameter

Blend Ratio % (Cotton/Acrylic)	N	Subset	
		1	2
40/60	270	.2578	
50/50	270	.2589	
75/25	270		.2722

Table 9. Tukey multiple comparison test of twist factor on yarn diameter

Twist Factor α_e	N	Subset		
		1	2	3
4.5	270	.2500		
4.0	270		.2611	
3.5	270			.2778

Table 10. Tukey multiple comparison test of yarn count on yarn diameter

Yarn Count Ne	N	Subset		
		1	2	3
30	270	.2356		
24	270		.2656	
20	270			.2878

The diameter differences between yarn count groups were analyzed according to Tukey multiple comparison test (Table 10). It was obtained that there is a significant difference between the yarn diameter values of each yarn count. It is also seen that the yarn diameter value increases as the yarn count decreases that means courser yarns. This situation is expected because of yarn structure. When the yarn count decreases (gets courser), the higher number of fibers will be inserted in unit length and so greater yarn diameter will be obtained.

3.3. Yarn Packing Density Results

Table 11 shows the packing density values of the yarn samples. The yarn packing density were analyzed according to blend ratio, twist factor and yarn count in Figure 9. When all yarn samples were examined, it was clearly seen that the packaging density increase with increase in the twist factor. Similar relationship between twist factor and packing density was also revealed by Taheri M. et all. [10]. It was stated that for a given yarn count, assuming the yarn cross-section is negligible, higher twist factor cause higher pressure from the surface to internal fibers, which results in a more packed cross-section and hence higher packing density [10]. According to the comparison of the yarn samples in terms of blend ratio, it can be revealed that yarn packing density generally increases as the cotton content increases. This finding can be attributed to the cross-section shape of cotton and acrylic fibers. The kidney shaped cotton fiber allows higher compression and packing in a unit area than that of dog bone shaped acrylic fiber. The study on the effect of constituent fibers on yarn packing density has also been investigated by Sinha et al. [30]. They also found a similar result and proved that cross-section shape and other factors deciding the compatibility of blend constituents influence the degree of packing.

It was stated that the mixing of non-circular fibers with circular fibers is likely to disrupt the uniformity in the distribution of the masses and thus affect the packing of the fibers. The study [30] revealed that non circular cross section of PVA cause hindrance in close packing.

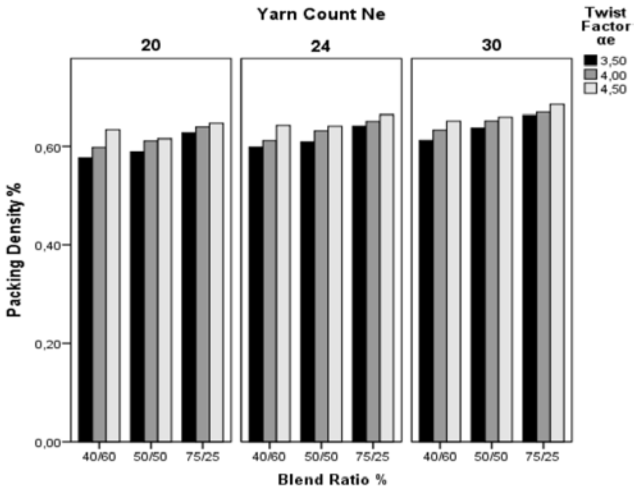


Figure 9. Packing density of yarn samples

According to the variance analysis (Table 12); all independent parameters; yarn count (Sig = 0.000), twist factor (Sig = 0.000) and blend ratio (Sig = 0.000) have significant effect on the yarn packing density values within 95% confidence interval. When F values are examined, it is seen that the maximum effect was obtained with blend ratio (F = 17.840).

Table 11. Packing density values of yarn samples according to fiber blend ratio

40/60 % Cotton/Acrylic								
	3.5 α_e			**4 α_e**			**4.5 α_e**	
30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
0.61	0.60	0.58	0.63	0.61	0.60	0.65	0.64	0.63
50/50 % Cotton/Acrylic								
	3.5 α_e			**4 α_e**			**4.5 α_e**	
30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
0.64	0.61	0.59	0.65	0.63	0.61	0.66	0.64	0.62
75/25 % Cotton/Acrylic								
	3.5 α_e			**4 α_e**			**4.5 α_e**	
30/1	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**	**30/1**	**24/1**	**20/1**
0.66	0.64	0.63	0.67	0.65	0,64	0.69	0.66	0.65

Table 12. Yarn packing density ANOVA result

Tests of Between-Subjects Effects						
Dependent Variable:	**Packing Density**					
Source	**Type IV Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Partial Eta Squared**
Blend Ratio	.195	2	.098	**17.840**	**.000**	.044
Twist Factor	.136	2	.068	12.400	**.000**	.031
Yarn Count	.176	2	.088	16.040	**.000**	.039
Error	4.284	783	.005			
Total	329.189	810				
Corrected Total	4.820	809				
a. R Squared = .111 (Adjusted R Squared = .082)						

According to the comparison analysis in terms of blend ratio groups (Table 13), it is seen that there is a significant difference between the packing density values of 75/25 blend ratio and other two blend ratios of 40/60 and 50/50 cotton/acrylic. There is no difference between the yarn packing density values of the yarn samples with the blend ratio of 40/60 and 50/50 cotton/acrylic. The lowest yarn packing density value was obtained in the blend ratio of 40/60 cotton/acrylic, while the highest yarn packing density value was obtained in the blend ratio of 75/25 cotton/acrylic. As proved from Table 13, higher cotton ratio leads to greater packing density in yarn cross-section.

According to the Tukey comparison for twist factor groups (Table 14), there is a significant difference between the yarn packing density values of all twist factor groups. It can be clearly seen that there is a direct proportion between packing density and twist factor. So, yarn packing density values increases as the twist factor increases. This result was attributed to the fact that the level of transverse pressure is influenced by the level of twist [30]. According to finding by Jiang et al. [13], the fibers are distributed in a less scattered way with increased twist factor, and this makes the whole yarn structure more compact.

Table 13. Tukey multiple comparison test of blend ratio on packing density

Blend Ratio % (Cotton/Acrylic)	N	Subset	
		1	2
40/60	270	.6173	
50/50	270	.6271	
75/25	270		.6540

Table 14. Tukey multiple comparison test of twist factor on packing density

Twist Factor α_e	N	Subset		
		1	2	3
3.5	270	.6170		
4.0	270		.6328	
4.5	270			.6487

Table 15. Tukey multiple comparison test of yarn count on packing density

Yarn Count Ne	N	Subset		
		1	2	3
20	270	.6512		
24	270		.6321	
30	270			.6151

The packing density values were statistically compared in terms of yarn count in Table 15. According to the Tukey table (Table 15), there is a significant difference between the yarn packing density values of each yarn count. There is a direct proportion between packing density and yarn count, so it can be said that as the yarn gets finer, the yarn packing density decreases vice versa. This result is similar to the previous studies performed by [10,13,24,27,28]. According to both theoretical and experimental measurements, it was found out that the courser yarns signify that they have more fibers in their cross sections and so the total compressive load acting on the yarn leading to increased packing density [13].

4. CONCLUSION

The most important challenge of the study is revealing effect of yarn physical properties such as yarn count, blend ratio and twist factor on yarn packing density, diameter and fiber migration properties for blend yarn. This study proposes a detailed analysis for yarn samples consists of two fiber components.

In 40/60 and 50/50 cotton/acrylic blend ratios, the cotton fibers placed toward the inner part of the yarn and acrylic placed toward the yarn surface. In the blend ratio of 75/25 cotton/acrylic, acrylic fibers move toward the inner part of the yarn and cotton fiber locates toward the yarn surface. It was proved that the blend ratio has significant effect on fiber migration property. It was revealed that the yarn structure can be designed according to the migration property of corresponding blend ratio. For example, the colored fiber constituent can be placed to the outer side and the gray fiber can be positioned in the core. On the other hand, the fiber with soft hand touch and higher moisture regain can be distributed to the outer surface and the stiffer and stronger fiber constituent can be located to the inner side of the yarn cross-section.

It was revealed that three of yarn independent parameters; blend ratio, twist factor and yarn count have significant effect on yarn diameter. The most prominence property among all independent parameters was determined as yarn count. As it is expected from the spinning technology, the yarn diameter decreases with the increase in yarn count (finer yarns). It was observed that the cotton content in the yarn structure leads to higher yarn diameters for finer counts. Since the higher twist factor causes higher radial force on the yarn structure, the diameter of the yarn decreases with increased twist factors.

Direct proportion between cotton content and yarn packing density was determined. As, the cotton ratio increases, the yarn packing density value also increases. The higher twist factor leads to higher packing density. This result can be attributed to the higher radial forces caused by the higher twist factor and hence the higher compression effect on the fibers. There is an inverse proportion between yarn count and packing density. As the yarn count increases i.e., the yarn becomes finer, packing density decreases. It was found out that the courser yarns include higher amount of fiber in their cross sections and so the higher compressive load acting on the yarn leading to increased packing density.

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