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# Denim Fabrics Woven with Dual Core-Spun Yarns

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Additional information is available at the end of the chapter

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## Abstract

Elastic core-spun yarns which is used as weft yarn for textile fabrics gained great importance in the last decade its due to the fact that stretch and recovery, comfort fits and flexibility properties. The technological progress made the dual core-spun yarn production possible. The dual core-spun yarns are composed of filament that contributes durability and polyurethane based elastane that provides stretchability to the fabrics. Hereby, both filament and elastane characteristics have great influence on denim performance at the same time. The main purpose of this study is to achieve the effect of filament fineness and elastane draft on denim fabric performance such as breaking force, breaking elongation, tear force, vertical elastic recovery, moisture management that is wicking rate and water absorption properties. Meanwhile, filament core-spun yarns with different filament fineness and 100% cotton yarn were also used as weft of the denims in order to investigate the differences statistically. It was found that that filament fineness and elastane draft had statistically significant effect on all inspected performances of denim fabrics except water absorption.

**Keywords:** denim fabric, dual core, multicomponent yarn, ring spinning system, microfilament

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## 1. Introduction

In the clothing industry, denim has a wide acceptance with high potential uses as a fashion trend all over the world. Generally, denims are woven with a construction of 3/1 twill and they consist of indigo dyed warp yarns interlaced with gray weft yarns. Denim fabrics are rigid and durable. Denim market has great market size at a value of \$57,312.5 million in 2016, and it is forecasted that the denim market will have an annual growth rate of 6.4% during

the forecast period. The denim sector with largest contribution rate to the global revenue with higher preferable products among the teenagers and adults, will expected to continue in growing in the future jean market [1].

With so much preference, denim sector has to constantly evolve the fabric properties to meet consumer needs such as flexible, shape retention, low abrasion resistance and comfortable to wear in use at all times. High competitive potential in this sector pushes the companies to offer opportunities of different fiber, functional yarns use which contribute fabric properties. One of the best offered way which response to these requirements is using core-spun yarns. These yarns are produced by wrapping sheath fibers around filament or staple fiber core with a certain twist [2, 3]. Incorporating core part within the yarn structure makes the yarn cheaper, stronger and qualified, besides, sheath fibers are conserve the traditional appearance, handle and comfort properties. It is exemplified as using cotton covered elastic core-spun yarn is a good example to enable free movements and at the same time provide higher fabric comfort with cotton in the yarn structure [4].

In the literature, many researchers have been focused on elastane containing core-spun yarns in terms of elastane draft, elastane ratio, elastane linear density, elastic yarn positioning, twist factor etc. in order to obtain optimum yarn properties [2, 5–18]. When twist factor increases, it will affect the tensile properties of elastic cotton core-spun yarn positively [12, 18]. Elastane draft and ratio are important factors influencing the yarn's mechanical properties. Elastane ratio influences the tenacity and elongation at break of wrapped elastane core-spun yarns with the same twist factor. In that way, the core-yarn's tenacity and elongation decreased while the elastane percentage increased [8, 9, 18]. Elastane draft effects breaking tenacity and elongation [10]. On the other hand, higher draft ratio causes decrease in elastic recovery of elastic core spun yarn [6]. Proper tension control of elastane and use of a thread guide device helps to keep the spandex at the center of the yarn, thereby improving the quality of the elastic core-spun yarn [18]. Elastic yarn positioning in the yarn construction is another important parameter on yarn characteristic [5, 9].

Besides using of elastic core-spun yarn, filament core-spun yarns are also widely used in order to enhance some characteristics of fabric i.e. durability, esthetic and functional properties. Filaments used for filament core-spun yarns can vary such as polyester, polyamide, polybutylene terephthalate (PBT), T400<sup>®</sup>, polypropylene etc. Sarioglu and Babaarslan studied on physical properties of filament core-spun yarns having different filament fineness (conventional, fine and micro) and yarn linear density. False twist textured polyester filaments with different fineness were used and cotton covered polyester filament core-spun yarns were manufactured by modified ring spinning system. They concluded that filament fineness and yarn linear density had a great influence on yarn breaking strength and elongation. Higher core ratio was found to have higher strength and elongation. In addition, filament fineness had a significant effect on the unevenness properties and it was determined that there was no statistical effect on imperfections except for yarn linear density parameter. Thus, it can be said that filament core-spun yarns have got better performances in comparison to 100% combed cotton ring spun yarns except hairiness properties [19]. Erez and Çelik investigated the influence of both twist factor and filament blend ratio (core-sheath ratio) on properties and liveliness of cotton wrapped polyester filament core-spun yarns. They found that twist factor and core-sheath ratio had a significant effect on yarn strength, elongation, hairiness, liveliness and diameter [20]. Jeddi

et al. studied both structural and physical properties of cotton covered nylon filament core-spun yarns with different twist factor and filament pretension [21]. Mahmood et al. stated that the best results for yarn strength of cotton covered nylon monofilament core-spun yarn were obtained at minimum twist factor and lowest spindle speed [3]. Shanbaz et al. studied on cotton covered polyester filament core-spun yarn on a modified ring frame to obtain the effectiveness of percentage of filaments in the blend, twist factor, positioning of roving on count, lea yarn strength and count strength product. Twist factor and roving positions have highly significant influence on count, lea strength and count strength product [22]. Similarly, Çelik et al. determined the influence of both twist factor and filament blend ratio on strength of yarn with the same materials. When sheath percentage increased, higher unevenness and lower hairiness were obtained [23]. Rameshkumar et al. investigated the core positioning on sheath coverage, core sheath ratios and plying effects on yarn and knitted fabric properties using polyester filament and waste silk. Tenacity, elongation and  $CVM$  of yarns also improved with increasing the core components. The core positioning at the center had lower tenacity with respect to right and left positioning. Thermal conductivities of silk rich (67% silk) fabrics were higher in comparison polyester rich (37% silk) fabrics. It was proved that polyester rich core-spun yarn fabrics show higher wicking [24]. Pramanik and Patil compared with cotton covered with crimped and drawn polyester filament hard-core ring and air jet yarns and 100% cotton ring yarn. It was concluded that using filament as core improved strength, elongation of filament core-spun yarns and ring spun and air jet spun yarns showed better performance with respect to 100% cotton ring-spun yarn [25]. Polyvinyl alcohol (PVA) is another filament used as tracer fibers in production of core-spun yarn. PVA is a water soluble filament, can be extracted from yarn structure by hot water easily. After extracted PVA filament from core-yarn, higher elongation, but similar breaking strength can be obtained when compared with typical ring yarns [26].

With technological progress and rising demands to obtain durable and long lifetime fabric, now the use of multicomponent core-spun (dual core-spun) yarns which enables elasticity and durable at the same time available. In other words, dual core-spun yarns consist of two core components; filament and elastane. In the production of the dual core-spun yarns filaments used can be polyester, T400®, polybutylene terephthalate (PBT) etc. In order to obtain dual core-spun yarns, additional creel loading of filament apparatus should be added to the current spinning system. As seen in the literature, there are lots of studies in terms of elastic core-spun and filament core-spun yarns with different materials.

Hua et al. developed elastic core-spun yarn containing a mix of spandex and polyethylene terephthalate/polytrimethylene terephthalate (PET/PTT) bi-component filament as core to obtain better yarn properties, especially for elastic property. In this study spandex draft ratio and linear density were selected as parameters and results showed that yarn stress decay,  $CVM$  value of evenness, and hairiness decrease when PET/PTT bi-component filament and spandex filament were used together as core. Furthermore, better yarn evenness was obtained by using PET/PTT bi-component filament and spandex filament core [27]. Telli et al. studied on fabrics containing tungsten in order to contribute alternative electromagnetic shielding. The fabric samples with three different yarns as core; Inox, Copper and Tungsten wires and three different double core-spun yarns with elastane and metal wires were produced. Electro Magnetic Shielding Effectiveness (EMSE) performances of fabrics were then evaluated [28].

With all these progresses show that the production of alternative functional fabrics has become possible with the use of dual core-spun yarns within the fabric structure. El-Tantawy et al. investigated the pilling properties of fabrics produced from dual core-spun yarns with and without welding process. Elastic core-spun yarn was also produced to determine the differences. They found that both types of dual core yarns exhibit less pilling than the core spun yarn fabrics [29]. Bedez Ute was focused directly on mechanical and dimensional properties of denim fabrics made from double core and core-spun weft yarns used at different densities. It was concluded that weft density effect was higher than weft yarn composition for mechanical and dimensional properties of denim yarns [30].

It is envisaged that researches will be developed in the production of different yarn compositions, so the use of dual yarns in denim fabric production will probably become widespread due to its advantages properties with respect to conventional ones. This study was carried out in order to contribute to the use of dual core-spun yarns in denim fabrics and bring a different perspective. This is experimental study is designed in order to compare breaking force, breaking elongation, static tear force, elastic recovery, moisture management i.e. vertical wicking and water absorbency rate of twill 3/1 denim fabrics made from cotton covered filament, both filament and elastane core-spun yarns and 100% cotton yarn in weft.

## 2. Materials and methods

### 2.1. Materials

This study was conducted about the performance of denim fabrics containing dual core-spun yarns with filament fineness and elastane draft ratio variables. In that respect, the properties of drawn textured polyester filaments with conventional, fine and micro fineness are given in **Table 1**. All polyester (PET) filaments were selected among the most commonly used commercial types which are named as stretch textured yarns. Since microfilaments are sensitive to heat and it is necessary to omit the second heating zone during texturing, the PET filaments are in set form.

Basically, the study was focused on three different yarn types such as 100% cotton (Co) yarn, cotton covered filament core-spun yarn by using 110 dtex PET filament with different filament fineness as a control variables, and also cotton covered dual core-spun yarns by feeding 110 dtex PET filament with different filament fineness and 78 dtex elastane filament as core within the yarn structure. In the yarn production, cotton fiber with the physical properties of 28.53 mm staple length, 4.56 micronaire fineness, 31.53 gf/tex tenacity and 28.53% elongation was used as a sheath fiber.

#### 2.1.1. Yarn and denim fabric production

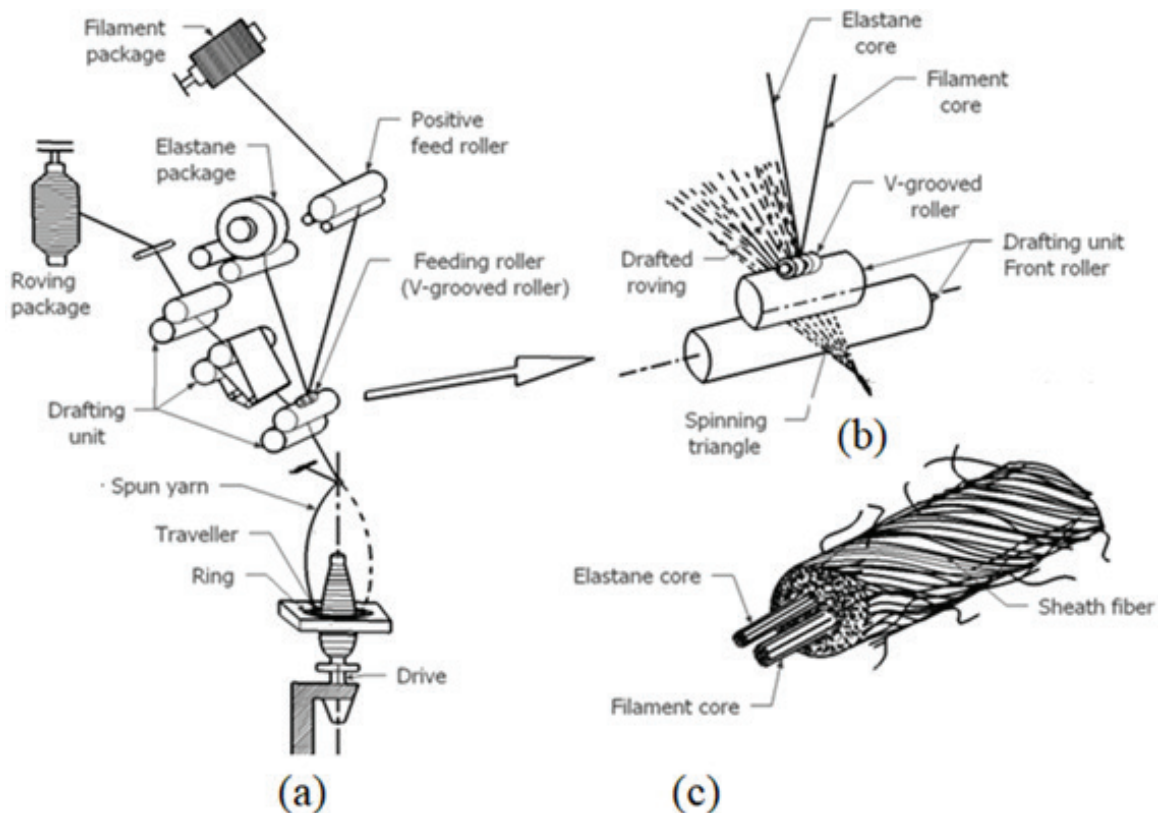
Dual core-spun yarn samples were produced with modified ring spinning system which was designed by adding an extra creel for facilitating both elastane and filament feeding at the same time as a core. Schematic representation of dual core-spun yarn production, combination of materials and cross-sectional view of yarn are illustrated in **Figure 1(a–c)**, respectively.



As seen from this **Figure 1**, both PET filament and elastane are driven by positive feed roller, separately. These components are fed to the nip point of the front rollers by means of V-grooved roller and at the same time cotton fiber wraps over these components, as well (**Figure 1b**). Thus, the draft of PET filament and elastane are achieved by speed difference between yarn delivery and front roller of drafting unit. Here, PET filament draft was kept constant as 1.08. On the other hand, draft of elastane was varied with 2.9, 3.2, 3.5 and 3.8. In doing so, 16 Co/PET/Elastane dual core-spun yarn samples were obtained with two different cores in order to benefit from these properties.

Parameters	Conventional	Fine	Micro	
Linear density (dtex)	110	110	110	110
Number of Filament	36	96	192	333
Tenacity (cN/dtex)	4.07	3.90	3.45	3.80
Elongation (%)	22.65	23.66	21.85	26.84
Crimp Stability (%)	85.93	84.08	78.50	77.32
OPU (%)	1.16	3.02	2.24	2.52
Intermingling (number/m)	52.40	76.10	73	67.60

**Table 1.** PET filaments properties.



**Figure 1.** Schematic illustration of modified ring spinning system, positioning the PET/elastane core at the nip point of the front roller, double core-spun yarn view (It may not be reproduced without permission); (a) modified ring spinning frame, (b) combination of materials, (c) simulated longitudinal and cross-sectional view of double core-spun yarn containing filaments.

In the production of the PET filament core-spun yarns, same system was used without extra elastane feeding and all production parameters were kept constant. Moreover, 100% Co ring spun yarn was also produced without both PET and elastane feeding. Combed cotton roving with 844 tex linear density was used for the production of all yarn types in order to produce 42 tex yarn samples at 9500 rev/min spindle speed and 660 turns/m twist.

These yarn samples were used as weft yarn and indigo dyed 100% Co ring spun yarn with 59 tex linear density was used as a warp yarn. Twill denim fabrics with 3/1 pattern were manufactured at constant structure parameters such as; 26 ends/cm warp density, 20 picks/cm weft density, 480 rev/min weaving machine speed, 180 cm reed width, 65/4 reed number. After the denim fabric production, singeing, desizing and finishing processes and thermal fixation processes were carried out. Finally, 21 different denim fabric samples were obtained. Design of experiment for denim fabrics is shown in **Table 2**.

## 2.2. Methods

Denim fabric samples were conditioned in standard atmosphere conditions at  $20 \pm 2^\circ\text{C}$  temperature and  $65 \pm 4\%$  relative humidity for 24 hours in accordance with BS EN ISO 139 standard [33]. Tested denim fabric properties, related standards and test procedures are illustrated in **Table 3**.

Fabric type	Filament fineness (dtex)	Elastane draft
100% Co denim	—	—
Filament core-spun denim	3.05, 1.15, 0.57 and 0.33	—
Dual core-spun denim	3.05, 1.15, 0.57 and 0.33	2.9, 3.2, 3.5 and 3.8

**Table 2.** Design of experiment for denim fabric samples.

Properties	Standard	Procedure
Fabric weight	ISO 3801	100 cm <sup>2</sup> of each fabric were cut with dies and weighed on a precision scale and then multiplied by 100. The fabric weight was calculated in g/m <sup>2</sup> .
Fabric thickness	ISO 5084	Thickness measurements for each fabric samples were taken by means of digital thickness tester.
Warp and weft density	BS EN 1049-2	The numbers of warp and weft yarns in 1 cm were determined for each fabric samples.
Breaking force and elongation	BS EN ISO 13934-1	Breaking force and elongation for both warp and weft direction were determined at 200 mm gauge length, 100 mm/min test speed.
Static tear force	BS EN ISO 13937-2	Test samples were prepared in accordance with single-tear method. Tests were performed for warp and weft yarns, separately, for each specimen at 100 mm/min test speed.
Elasticity	BS EN 14704-1	To determine the elasticity properties of fabrics, Method A was used. The number of the cycling load was 50 cycles (instead of 5 cycles because of detecting elastic recovery under higher number of cyclic loading) with applying load of 6 N/cm width of the fabric.

**Table 3.** Test standards used and procedure achieve to determine denim fabric properties.

### 2.2.1. Moisture management

“Moisture Management” includes all the terms of wicking, wetting, absorbency or transportation and these properties of the fabrics are related to the ability of a textile fabric to transport moisture away from the skin to fabric’s outer surface in multi-dimensions. Wetting and wicking are considered as the most important parameters for absorption and transportation of liquid in textile clothing [31].

Wicking is the flow of a liquid in a porous substance in time which is driven by capillary forces [33]. Vertical wicking rate was conducted by various researchers in different ways [31–36]. In this study, to evaluate vertical wicking properties of denim fabrics, 20 cm × 2.5 cm strip test specimens for warp and weft direction were prepared. Denim fabrics were suspended vertically with its 3 cm of lower end immersed in a reservoir of distilled water colored with 0.01 g red dye to observe the rate of the uptake of the liquid easily. Because of the high areal density of denim fabric samples, to be tested pretension was applied with two clips totally to ensure 2 g of dead load. The wicking height of liquid rising was measured after 30 min time intervals and wicking rate was determined as mm/s. Wicking tests were conducted with five samples for both warp and weft directions of each fabric. In order to complete the wicking tests more quickly, a new wicking apparatus design was made (**Figure 2**). The designed apparatus consists of five clamps for sample hanging, five rulers placed next to the fabric samples for height measurement and reservoir. Since it is planned that five specimens will be applied to vertical wicking test procedure for each sample, such an apparatus is designed and manufactured in order to complete the wicking tests in shorter time.

Wettability terms is explained as the first impression of fabric when get into touch with liquid. When the fabric is wetted the interaction between the forces of cohesion (within the liquid) and the forces of adhesion (between the fibers and the liquid) determines whether wetting takes place or not and also determines spreading and absorption of the liquid over the surface of the textile material [31]. In order to determine the absorption areas of the fabrics after 0.2 ml water was dropped, image analysis was conducted by using camera to catch the visual after 2 min.

In order to determine the absorption rate and area of the fabrics wetted, image processing method was used. For this aim, an image acquisition system was built up. The system consists of a digital microscope camera, lightening system, camera attachment equipment and computer (**Figure 3**). Since the liquid existence within the fabric structure will lead to different light transmission level in comparison to dry regions, it was considered that the dry and wetted regions can be distinguished by applying a logical threshold operation in accordance with the pixel light intensity values. So, the back lightening system was selected for this study.

The denim fabric samples were placed over the lightening unit. The colored solution with 0.2 ml volume was dropped on the fabric sample by means of a screwed syringe. At the same time, the video acquisition of the digital microscope camera was started. The image frames with the size of 640 × 480 pixels were snap shotted at instant of solution drop fell on the sample and 2 min after dropping. These image frames in JPG format were acquired from three different parts of each fabric sample. The acquired image frames were analyzed by means of a developed algorithm (**Figure 4**).



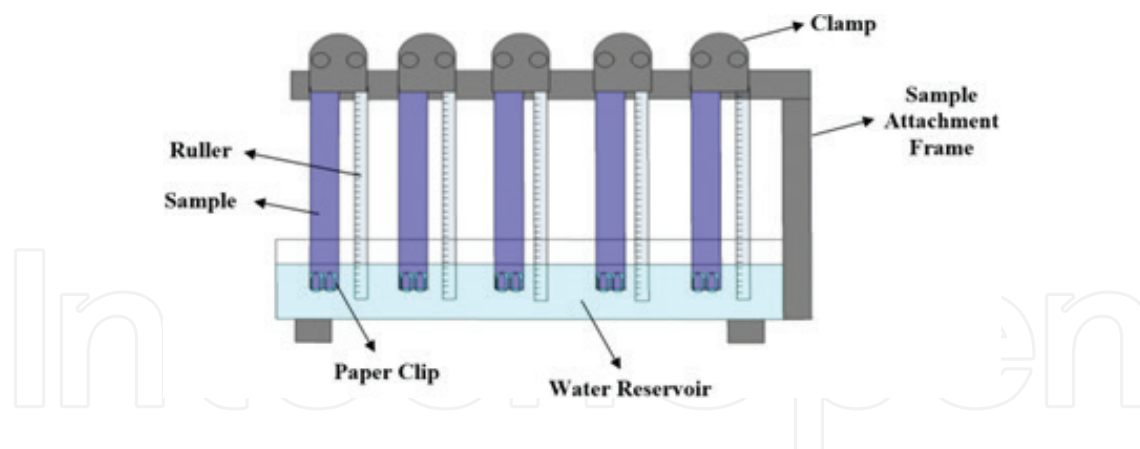


Figure 2. Vertical wicking apparatus.

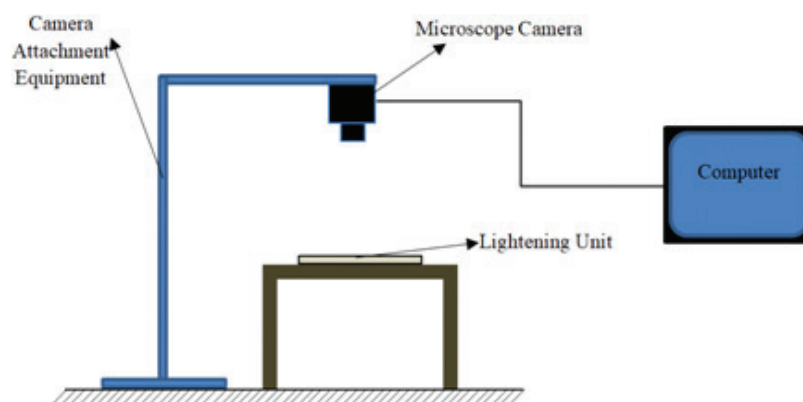


Figure 3. Image acquisition system.

First of all, the color image frame in RGB format was converted into gray scale. Then, the image enhancement operations such as noise removing and smoothing were applied by using average and Gaussian filters respectively. Gaussian smoothing commonly forms the first stage of an edge-detection algorithm [37]. The average filter is useful especially for removing Gaussian noises. In order to eliminate the noises caused from lightening condition and electrical reasons, the noise removing filters are applied [37]. The enhanced image frame was converted into binary form by applying a suitable threshold value. All pixel values of the filtered gray image were replaced with the value 1 (white) when the corresponding pixel value greater than threshold level, otherwise it was replaced with the value 0 (black). The white pixels in the binary image correspond to the liquid absorbed area and the black pixels correspond to dry area. In order to determine the exact absorption area and remove the other unnecessary parts, opening morphological operation was applied. Morphological opening is erosion followed by dilation, using the same structuring element for both operations. The opening operation has the effect of removing objects that cannot completely contain the structuring element. Boundary of the absorption area was labeled by means of “canny” edge detection method. Finally, the area of the absorption region was calculated. The absorption rate of each denim fabric sample is calculated as the percentage of white pixels to the whole pixels of the binary image. The application results of the developed algorithm at the instant of drop fell and 2 min after dropping were given in Figures 5 and 6, respectively.

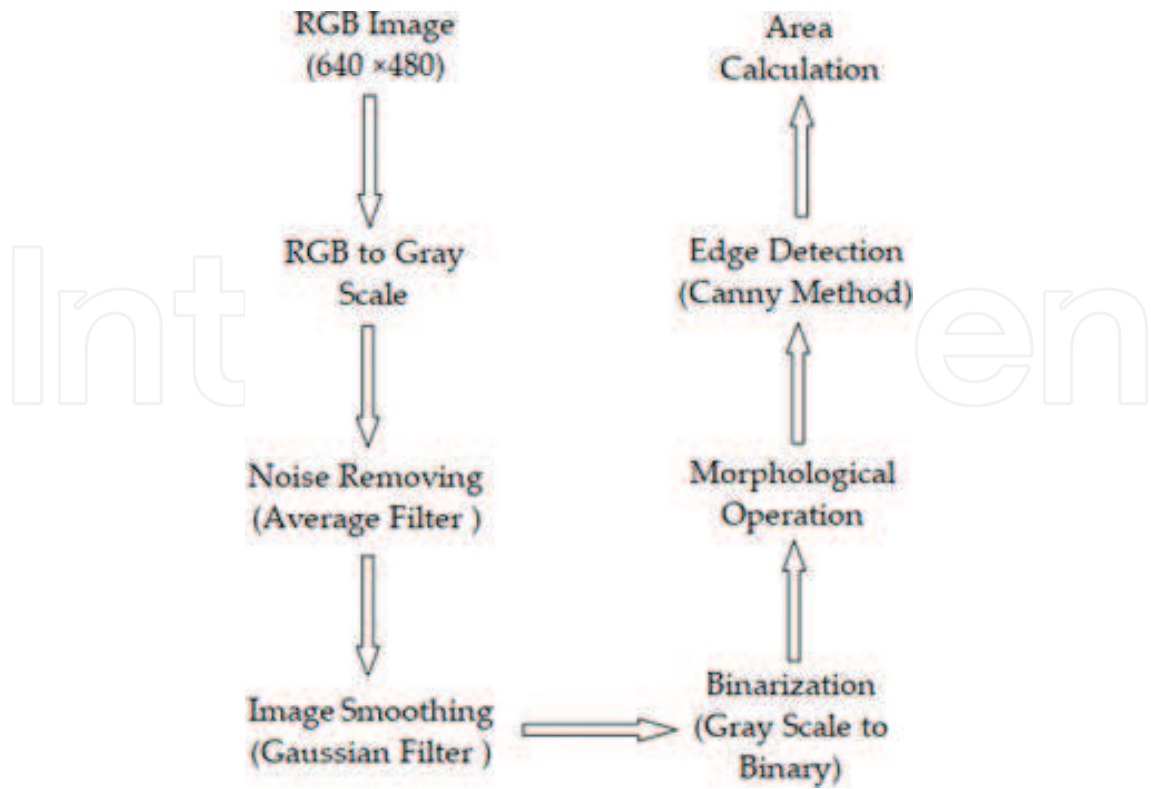


Figure 4. Absorption area calculation algorithm.

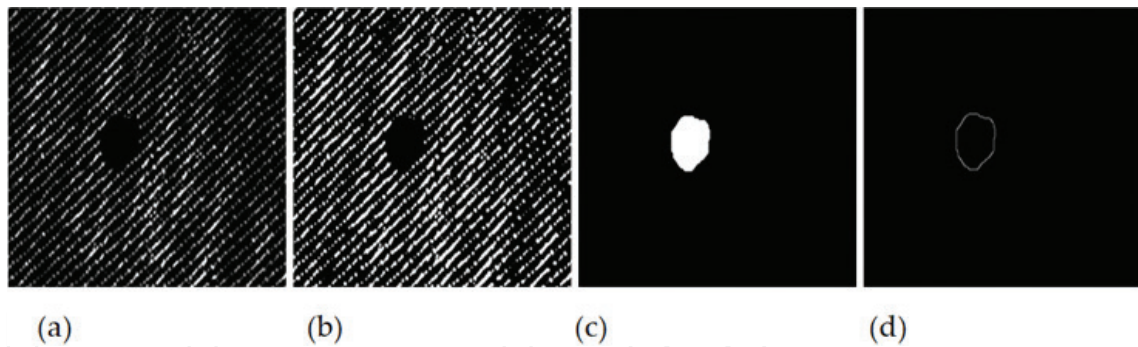


Figure 5. Absorption area at the drop fell.

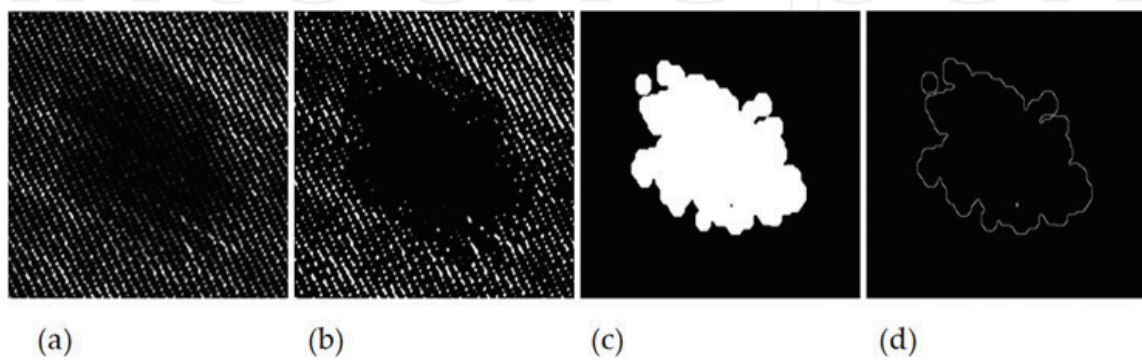


Figure 6. Absorption area 2 min after dropping.

### 2.2.2. Statistical analysis

In statistical analysis, multivariate analysis of variance (MANOVA) was achieved at 95% confidence interval by means of SPSS package program to determine whether there was statistically significant effect of the filament fineness, and elastane draft on denim fabric breaking force, breaking elongation, static tear force, elasticity, wicking rate and water absorption rate. The evaluated independent parameters were used as weft yarn in the denim fabric production so all response variables were analyzed in weft direction as well.

## 3. Experimental results

The structural properties of denim fabrics and test results are illustrated in **Tables 4** and **5**, respectively.

Fabric type	Filament fineness (dtex)	Elastane draft	Fabric weight (g/m <sup>2</sup> )	Fabric thickness (mm)	Warp density (ends/cm)	Weft density (picks/cm)
100% Co denim	—	—	310	0.68	29.6	22
Co/PET	3.05	—	320	0.71	29.8	22.4
Filament core-spun denim	1.15	—	320	0.74	29.6	22.8
	0.57	—	320	0.68	29.8	22.8
	0.33	—	330	0.70	29.8	22.4
Co/PET/elastane	3.05	2.9	342	0.83	32.4	22.8
Dual core-spun denim	1.15	2.9	355	0.81	32.6	22.8
	0.57	2.9	345	0.83	33	22.8
	0.33	2.9	352	0.79	32.4	22.8
	3.05	3.2	352	0.83	30.6	22.8
	1.15	3.2	351	0.80	32.8	22.8
	0.57	3.2	350	0.81	32.8	22.8
	0.33	3.2	357	0.83	32.6	23.2
	3.05	3.5	355	0.84	33.4	22.8
	1.15	3.5	360	0.83	33	22.8
	0.57	3.5	359	0.84	33	22.8
	0.33	3.5	360	0.84	33	22.8
	3.05	3.8	356	0.83	30.8	22.8
	1.15	3.8	354	0.84	33.4	22.8
	0.57	3.8	359	0.82	33.4	22.8
	0.33	3.8	365	0.82	33.6	22.8

**Table 4.** Structural properties of denim fabric samples.

### 3.1. Breaking force and elongation

To advance the comfort performance of the denim fabrics during body movement, dual core-spun yarns including elastane that provide higher elasticity and recovery are preferred. However, this advantage brings a disadvantage together and it leads to decrease in tensile strength of denim fabrics [30, 38]. The tensile test outcomes of the presented study is illustrated in **Figure 7** the breaking force of denim fabrics in weft wise composed of 100% Co, filament core-spun yarns and dual core-spun yarns.

It was clearly seen in **Figure 7** that denim fabrics made from filament core-spun yarns have the higher breaking forces than both 100% Co and dual core-spun denims. The highest breaking force was detected at 0.33 dtex filament core-spun denim fabric, this result is attributed to the fact that more filaments in the yarn cross-section can provide more resistance against tensile force. When the breaking forces of dual core-spun denim fabrics are taken into consideration in terms of effect of elastane draft, it is observed that the breaking force of samples with conventional firmament have increasing trend by increasing elastane draft. However, the fabric samples with micro fineness filament have decreasing trend with the elastane draft increase. Since increasing the elastane draft leads to decrease of elastane ratio within the fabric increase and so increase in breaking force of the fabric. However, this result is not clearly seen for dual core-spun denim fabrics due to involving both PET filament and elastane.

The breaking elongation of denim fabrics are shown in **Figure 8**. Elastane content contributes the elongation of the denim fabrics and this situation is clearly observed among the all fabric samples. Elongation directly affects the elasticity properties of the denim fabrics this is why elastane is used. The lowest breaking elongation was obtained with 100% Co denim fabric without both filament and elastane. When the denim fabrics made from filament core-spun yarns are investigated, it is seen that 3.05 dtex filament core-spun denim fabrics has the highest breaking elongation value and breaking elongation values of all filament core-spun denim fabrics are similar. From these results, it can be revealed that filament core part contributes strength of the fabric with an acceptable elongation value.

It can be possible to see how dominant the effect on the denim fabric elongation performance of the elastane draft ratio is. It is observed that with the increase of the elastic draft ratio, the breaking elongation of the fabric increases. This situation may be attributed to the fact that higher elastane draft may probably leads to increase in cohesion forces between filament, elastane and Co, and so breaking elongation can probably increase. Hereby, it can be said that elastane represents a large majority of the extensible part of fabric under the tensile force. In terms of filament fineness parameter of dual core-spun denim fabrics, it can be said that breaking elongation varies from 38.18 to 44.08%. The predominant elasticity property of elastane makes it difficult to see the effect of filament fineness in **Figure 8**, however, with statistical analysis effects can be examined in detail.

### 3.2. Static tear force

Static tear force in weft direction of denim fabric samples are illustrated in **Figure 9**.

According to tear force values, it is seen that 100% Co denim fabric has lower value than that of denim fabrics containing both filament and dual core-spun yarns. On the other hand, PET

Fabric type	Filament fineness (dtex)	Elastane draft	Breaking force (N)		Breaking elongation (%)		Static tear force (N)		Elastic recovery (%)		Vertical wicking rate (mm/s)		Water absorption (%)
			Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	Warp	Weft	
100% Co denim	—	—	1321.89	753.86	25.70	21.44	31.85	35.63	35.85	56.63	0.0496	0.0417	10.14
Co/PET	3.05	—	1372.94	864.41	26.16	26.08	56.96	47.29	41.98	78.02	0.0524	0.0500	23.72
Filament core-spun denim	1.15	—	1403.24	831.55	24.23	24.77	57.60	47.86	47.50	77.68	0.0419	0.0469	21.28
	0.57	—	1441.81	832.33	28.51	24.33	57.82	47.78	47.48	80.84	0.0317	0.0472	21.30
	0.33	—	1335.22	888.84	26.98	25.45	56.33	50.50	43.33	80.34	0.0498	0.0444	22.16
Co/PET/elastane	3.05	2.9	1604.25	739.35	32.21	39.39	56.90	42.93	51.61	91.62	0.0506	0.0511	21.98
Dual core-spun denim	1.15	2.9	1533.54	781.09	32.15	38.18	55.42	48.84	52.55	92.37	0.0457	0.0509	26.30
	0.57	2.9	1419.95	809.82	30.95	38.43	55.70	48.46	55.51	92.40	0.0467	0.0502	22.15
	0.33	2.9	1581.12	799.83	32.96	38.67	55.92	49.44	53.03	87.18	0.0481	0.0485	29.24
	3.05	3.2	1493.31	764.48	31.05	40.96	55.50	45.68	54.31	88.35	0.0480	0.0489	20.04
	1.15	3.2	1327.06	801.72	31.17	41.49	54.43	49.58	55.09	87.97	0.0426	0.0474	25.01
	0.57	3.2	1529.27	801.60	32.22	41.37	55.20	50.70	55.47	89.82	0.0333	0.0439	19.23
	0.33	3.2	1586.84	801.25	33.42	41.42	55.36	48.70	52.58	89.51	0.0385	0.0480	26.18
	3.05	3.5	1606.22	763.32	32.59	41.81	55.60	45.27	55.29	86.88	0.0487	0.0463	16.67
	1.15	3.5	1658.09	778.34	32.87	41.44	53.77	47.73	52.76	90.17	0.0472	0.0463	24.92
	0.57	3.5	1465.46	794.11	31.46	42.81	54.44	46.64	52.70	89.59	0.0461	0.0433	20.72
0.33	3.5	1632.86	777.56	32.33	41.67	55.07	46.27	53.75	90.76	0.0411	0.0457	29.30	
3.05	3.8	1611.52	760.10	31.48	44.08	55.93	44.28	39.53	89.85	0.0365	0.0478	17.34	
1.15	3.8	1547.79	792.34	32.23	42.47	54.81	48.49	46.89	91.24	0.0448	0.0485	28.47	
0.57	3.8	1572.50	779.58	31.80	44.00	53.35	46.64	50.12	90.82	0.0300	0.0507	21.13	
0.33	3.8	1574.92	784.28	31.58	43.23	53.96	47.39	50.40	90.38	0.0489	0.0474	28.07	

Table 5. Test results of denim fabric samples.



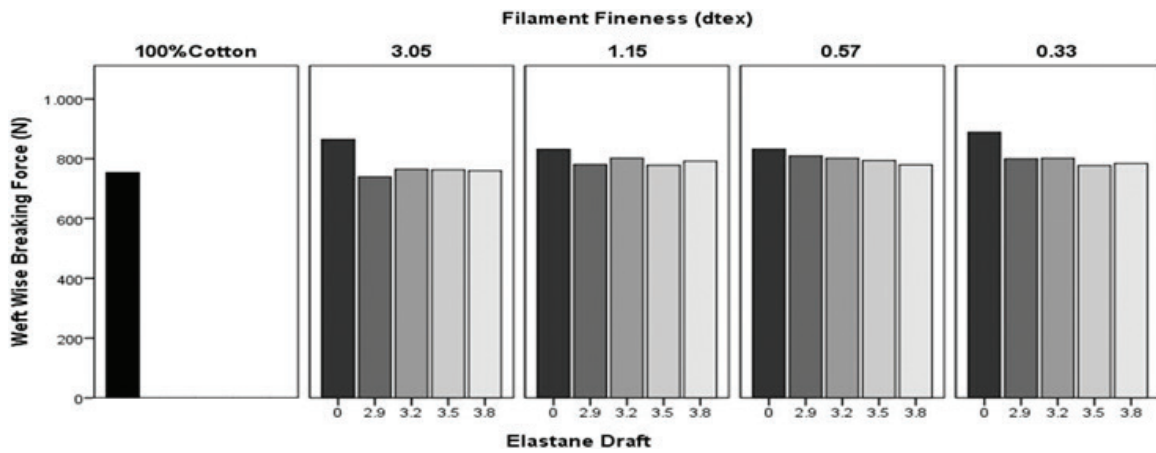


Figure 7. Weft wise breaking force of denim fabrics.

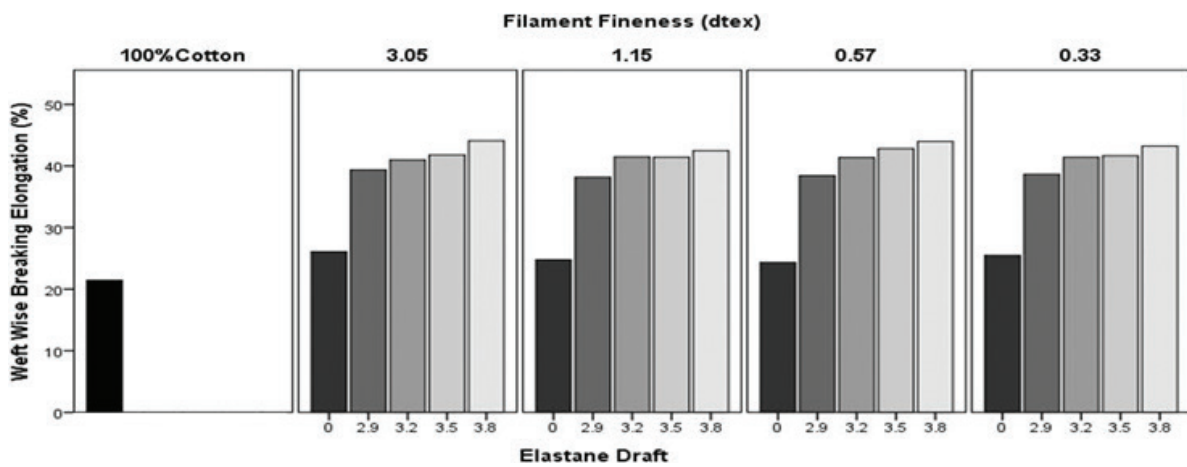


Figure 8. Weft wise breaking elongation of denim fabrics.

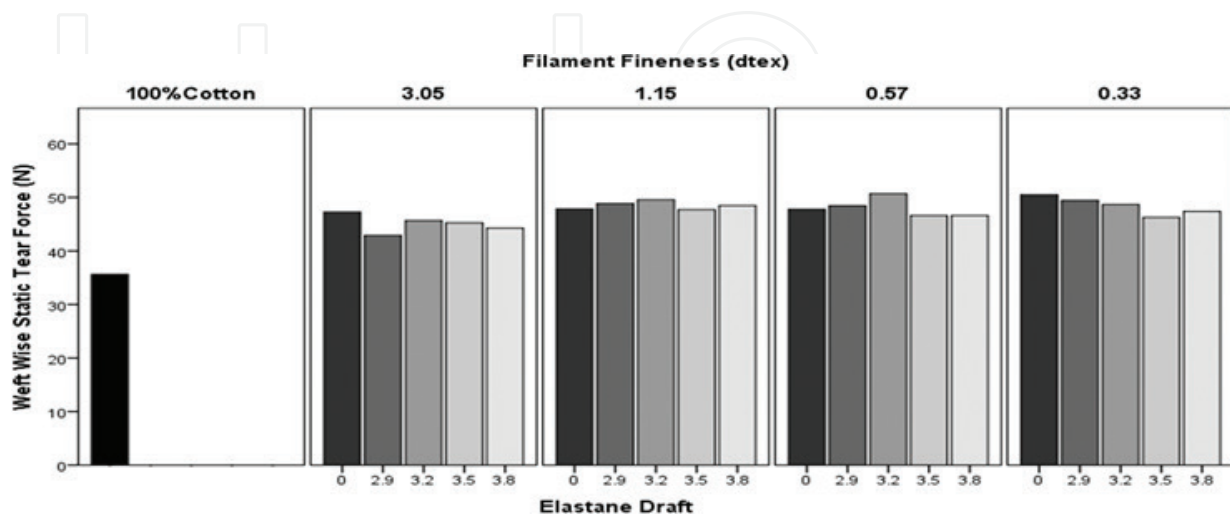


Figure 9. Weft wise static tear force of denim fabrics.

filaments from conventional to micro fineness contribute static tear force of denim fabrics except 0.57 dtex microfilament containing filament core-spun denim fabric. PET filament with 0.57 dtex filament fineness has the lowest breaking strength and so it can be said that filament properties affect the denim fabric properties as well. In addition, static tear force increases until 3.2 elastane draft ratio for all dual core-spun denim fabric types except 0.33 dtex filament containing dual core-spun denim fabric. Then, it is observed that after 3.2 draft value the increase in elastane draft effects static tear force negatively. Static tearing action leads to as the broken of the yarns individually or group. Hereby, increasing the elastane draft contributes tear force until 3.2 draft value because of the rising Co content. Furthermore, PET filament with fine and micro fineness contribute the tearing performance of the denim fabrics, because of the higher number of filament in the core of the dual core-spun yarns acts more resistance to break. This result can be explained with higher number of filament in the core of the dual core-spun yarns providing more resistance to break.

### 3.3. Elastic recovery

During usage of the denim should stretch freely in accordance with body movements especially at knee and should retain its original shape without any deformation after stretching. So that capability of extension and recovery of denim after repeated loadings is very important characteristics [39]. Higher the number of the loadings can contribute to life assessment in accordance with evaluating the fabric performance. Different from the test standard, 50 cycle loadings were carried out in order to evaluate elastic recovery of denim samples rather than 5 of cyclic loadings. Elongation after 50 cyclic loading and un-recovered elongation after 60 min recovery period were estimated according to Eqs. (1) and (2), respectively in accordance with BS EN 14704-1. Elongation,  $S$ , expressed as percentage:

$$S = \frac{E-L}{L} * 100 \quad (1)$$

where:  $E$  = extension (mm) at maximum force on the 50th cycles,  $L$  = initial length (mm).

Un-recovered elongation,  $C$ , expressed as percentage:

$$C = \frac{Q-P}{P} * 100 \quad (2)$$

where:  $Q$  = distance between applied reference marks (mm) after a specified recovery period,  $P$  = initial distance between applied reference marks (mm).

From Eqs. (1) and (2) elastic recovery of fabric can be expressed as following Eq. (3).

$$R = \frac{S-C}{S} * 100 \quad (3)$$

**Figure 10** displays weft wise elastic recovery of denim fabrics after waiting 60 min recovery period. It can be said that both filament and elastane improve stretchability and recovery properties of the denim fabrics when compared with pure Co ones.

In terms of elastic recovery value of denim fabrics, pure Co denim has the lowest stretchability properties. The presence of elastane contributes to elastic recovery with a high value approximately 85–90%. Dual core-spun denim fabrics have also higher elastic recovery than filament core-spun fabrics. In general it can be said that increase in elastane draft also increases the elastic recovery except 2.9 elastane draft. It is seen that denim fabrics have the highest elastic recovery at 2.9 elastane draft of 3.05, 1.15 and 0.57 dtex dual core-spun yarns.

### 3.4. Wicking rate

The wicking rate measurements in mm/s are presented in **Figure 11**. Weft wise wicking rate obtained for pure Co denim is lower than vertical filament core-spun denims. Vertical wicking rate of the filament core-spun denim fabrics decreases from 3.05 to 0.33 dtex. Since filaments are in the core part of the yarn, capillary transfer of water may not be fully observed during the period of time. This situation can be observed at the rest of the denim fabrics with different draft ratio. On the other hand, in general, the effect of the elastane draft can be seen

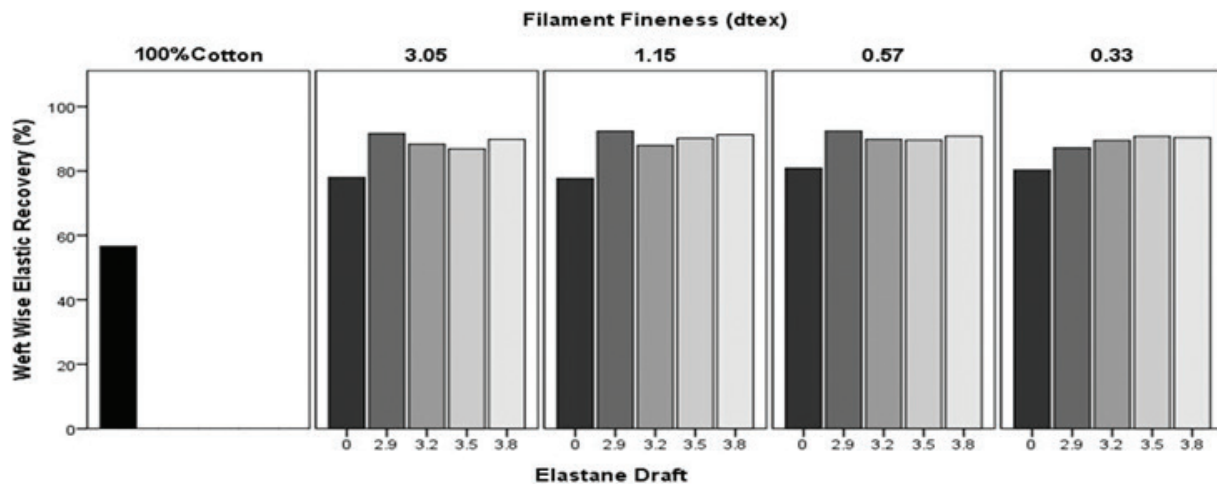


Figure 10. Weft wise elastic recovery of denim fabrics.

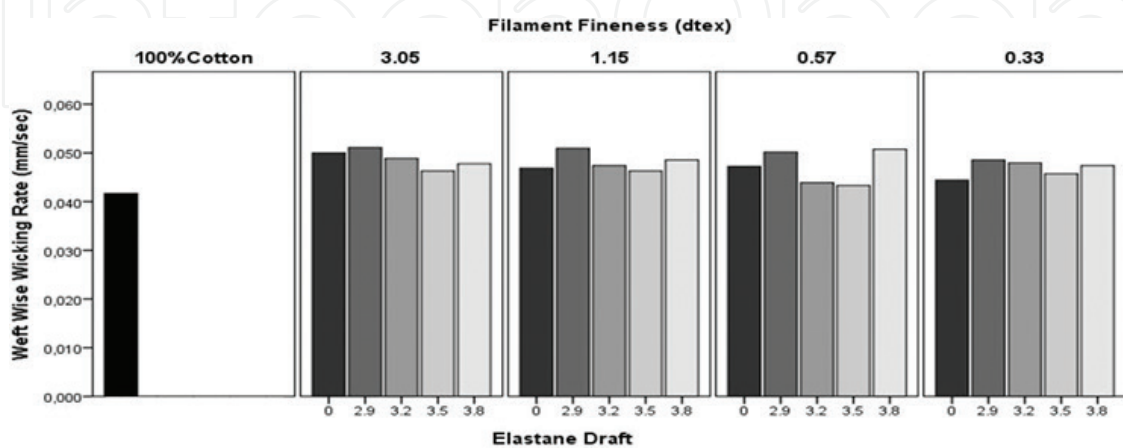


Figure 11. Weft wise wicking rate of denim fabrics.

as decreasing wicking rate of the denim fabrics. Decreasing in elastane draft causes increase in Co and it is known that Co absorbs the water instead of transfer, as well. In addition, it is also observed that increase in the number of filaments causes a decreasing wicking rate when the average of the values for each filament fineness including all elastane draft is taken into consideration.

### 3.5. Water absorption rate after dropping

Water absorption rate as percentage of the wetted area detected by image processing method by using MATLAB is illustrated in **Figure 12**. Naturally, it is known that the absorption of cotton fibers is better when compared to synthetic fibers. Water transfer occurs in synthetic fibers through capillary forces. So, the rate of absorption in pure Co denim i.e. the area of dropped colored water is found smaller after 2 min. On the other hand, it is seen that filament core-spun denim fabrics have at least two times greater absorption area than that of pure Co fabric. It can be said that the presence of PET filament leads to water or moisture transportation instead of penetration. It can be observed that there is no increase or decrease tendency of absorption rate of dual core-spun denim fabrics in terms of elastane draft. This situation can be explained with having different liquid transportation of fabrics depending on the filament fineness. Whereas the elastane has taken almost the entire stretch of fabrics, the PET filament here carries capillary properties of fabrics with its high capillary transport capability in moisture management.

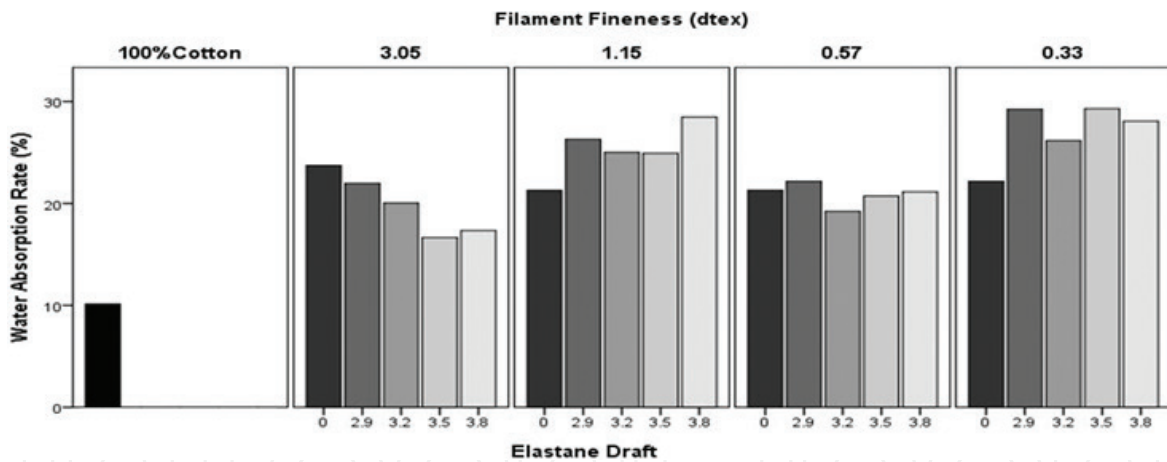


Figure 12. Water absorption rate of denim fabrics.

Independent variables	Breaking force (N)	Breaking elongation (%)	Static tear force (N)	Vertical wicking rate (%)	Elastic recovery (%)	Water absorption rate (%)
Filament fineness	0.000*	0.003*	0.000*	0.000*	0.000*	0.000*
Elastane draft	0.000*	0.000*	0.000*	0.000*	0.000*	0.077

\*The mean difference is significant at the 0.05 level.

Table 6. Multivariate analysis of variance (MANOVA) test results for weft wise properties of denim fabrics.

In analyzing of filament fineness effect, 3.05 and 0.57 dtex dual core-spun yarn denim fabrics including all elastane draft have the lower wetted area percentage with the average value of 19 and 20.8%, respectively. On the other hand, 1.15 and 0.33 dtex dual core-spun yarn denim fabrics including all elastane draft have higher wetted area percentage with the average of 26.2 and 28.2%, respectively. The highest wetted area was found as 0.33 dtex, it can be explained as higher number of the filaments enables more liquid transportation.

### 3.6. Statistical analysis

To put forward the influence of filament fineness and elastane draft parameters on denim fabric breaking force, breaking elongation, tear force, elastic recovery, vertical wicking rate and water absorption rate statistically, multivariate analysis of variance (MANOVA) was achieved at 95% confidence interval (**Table 6**). Statistical results indicate that filament fineness parameter has significant effect on all variables. Elastane draft has also significant importance on all depended variables except water absorption rate ( $p = 0.077$ ) at the 0.05 level.

## 4. Conclusion

Application of core-spun yarns in textile industry is in progress to improve physical and mechanical properties of fabrics, such as comfort, abrasion resistance, tenacity, durability, and functional properties. Stretch denim fabrics are mostly produced from core-spun yarns. Advanced stretching performance provides better fitting to body. Cotton is the most appreciable material as sheath component of the yarn which is responsible for comfort and esthetic properties. Denims' clothing and fitting to human body, comfortable and performance properties are essential for consumers. The most acceptable driving factors for denim market are consumer demand, rapid change of fashion and denim styles, highly preferred by young people and these factors are changing in very short period of time. When the overall consumption of denim in the world and market size are taken into consideration, value-added and high durable denims produced from functional yarns will response to the desired comfort and fit characteristics as well.

Since the denim fabrics have high demand in textile market and it is increasing day by day, this study is conducted to evaluate the developments in denim fabric production and submit an innovative case study to improve the performance of denim fabric. In day fashion trends, denim fabrics are now not only used for the jeans production, they are also used in the production of shirt, t-shirts, skirts, bags and different textile product accessories. Depending on the usage area of denim fabrics, different performances and functions are required from them. Different ways can be performed to improve the performances of the textile products. Using different pattern designs, selecting proper raw material, using specially produced yarns or applying finishing chemicals are effective treatments. The finishing and washing processes are applied to add higher hand property, better touch feeling and attractive appearance. Evidence in literature demonstrates that usage of different characteristic fiber and yarn is effective method to increase mechanical performance of the denim fabrics. The incorporation



of elastane and filament in yarn core gives new configurations to yarn geometry and ultimately changes the fabric geometry. Depending on developments in the yarn production technology, specially designed and functional yarns such as core-spun, filament core-spun and dual core-spun yarns are produced and widely used.

In this study, to design more attractive and higher performance denim fabric Co/PET/elastane containing dual core-spun yarns were systematically used in production. Furthermore, the effects of filament fineness and elastane draft on denim fabric performance were revealed. Filament core-spun yarns with different filament fineness and pure Co yarn were also produced to compare the performance of denim fabrics. These all yarn types were used as filling of denims. Breaking force, breaking elongation, static tear force, elastic recovery, vertical wicking rate and water absorption rate properties were inspected and results were analyzed statistically.

As expected from the structural properties of the core-spun yarns, incorporating filament contributes to breaking force of the denim fabric. On the other hand, it was observed that increasing elastane draft affects breaking elongation positively. This result is attributed to the fact that higher elastane draft leads to increase in cohesion forces between filament, elastane and cotton sheath. When dual core-spun denim fabrics containing PET filament with fine and micro fineness is considered, tear force raises from fine to micro fineness because of the higher number of filament in the core of the dual core-spun yarns and so higher resistance to break.

In order to propound the advantages of the core-spun yarn usage, the performance of pure cotton denim fabrics were compared. It was seen that denim fabrics from pure cotton has the lowest elastic recovery. These results exactly proved that core-spun yarns can improve the mechanical performance of the denim fabrics without sacrificing the good softness and feeling of cotton. When the effect of core-spun yarn structural parameters on denim elastic recovery performance were investigated, in relation to the statistical analysis, it was also presented that both filament fineness and elastane draft have significant effect. Elastic recovery of the fabric can be aligned as cotton denims < filament core-spun denims < dual core-spun denims. The results in this study also indicates that the core-spun yarns not only increases the mechanical performance, but they also advance the comport performance. Higher wicking and absorption rates were obtained with core-spun and dual core-spun yarn denims in comparison to pure cotton denim.

For the absorption rate calculation, a novel method based on image processing was developed. Thus, the absorption area calculation was achieved accurately. In this experience, it was determined that the irregular color hues of indigo dyed warp yarns made the measurement difficult. High fabric thread density also restricted this measurement. So, it is planned that the absorption rate of the fabric samples will be determined by using different light source and lighting condition in further study.

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