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Design of Hybrid Yarn with the Combination of Fiber and Filaments and Its Effect on the Denim Fabric Performance

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Abstract
Consumer choice and behavior are changing and focusing on comfortable clothing along with fitting. Elastic yarn or fabric is necessary to achieve this comfortableness. By making elastic yarn and using elastic material in fabric production, elastic cloths are produced with proper stretchability and recovery. For that, core-spun yarn was used, but due to a lack of recovery performance, dual core-spun yarn has been developed. Different elastane ratios, linear density, and filaments were used in the dual core-spun yarn according to achieve desired stretchability. In this study, denim fabric performances were evaluated by designing different composite/hybrid dual core-spun yarn with a combination of cotton fiber and filaments. Different elastane linear densities with different filaments, PET/PTT, PTT, and PET, were used, and it was found that using finer elastane in dual core-spun yarn, strength, and unevenness are increased, and elongation decreased. Using PET/PTT filament increases hairiness, and using PTT filament increases elongation. For fabrics, coarser elastane in the dual core-spun yarns has higher stiffness, elasticity, and shrinkage. Fabric with PTT showed higher weight change and stiffness, whereas PET filament-based fabric samples have good strength and low stiffness. In addition, a multiple regression analysis was carried out for yarn and fabric properties, and mathematical models were developed.

Keywords
Dual core-spun yarn, elastane, filament yarn, hybrid yarn properties, denim fabric performance.

1. Introduction

Day by day, fashion is changing, and, nowadays, consumers like to wear skinny dress, for which proper fit and good appearance of clothing play a vital role for acceptance. Fabric elasticity is the most significant factor when it comes to comfort, fit, and body movement. For example, denim jeans need 10-35% elasticity for better comfort at the time of body movement [1]. In recent years elastic fabric and garments usage has increased a lot, and to fulfill the demand, the usage of elastic materials has increased also. Consumers choose elastic garments over conventional ones due to their comfortability, stretch, recovery capability, and performance [2]. An elastic structure is required to improve the elasticity and recovery of the fabrics, and the elastic core-spun yarn is used to accomplish this purpose [3] as fabric properties mainly depend on its elements like fiber and yarn properties.

Core-spun yarn has at least two components, a sheath fiber, and core fiber. The core fiber is an elastomeric filament which is surrounded by the sheath fiber. Here sheath fiber is a staple fiber and has less elasticity than core fiber. With this arrangement, the yarn has all the sheath fiber properties and stretchability [3–7]. As core-spun yarn has some challenges like lack of recovery, dimensional change, and stability, a new generation yarn named dual core-spun yarn has been developed [8, 9]. Dual core-spun yarn is made of three components, and along with sheath fiber in the core, there are filaments and elastane [1, 10–12]. Here, elastane as a high elastic component helps to enhance the high elasticity, whereas semi-elastic filament helps to enhance high recovery, stability, and low shrinkage properties [8]. Figure 1 illustrates the cross-section view of core and dual core-spun yarns.

For the filament, PET/PTT (polyethylene terephthalate/polytrimethylene terephthalate), PET (polyester), PBT (polybutylene terephthalate), PTT (polytrimethylene terephthalate), etc., are used as a core component, and PET-based core yarn is used for attaining higher strength [13]. Elastane filament is used as a soft component and has a high elongation range of 400 to 800 %, with polyurethane segmenting the polymeric chains at 85 %. After removing the force on elastane, it can quickly return to its original form, whereas PET/PTT (T400®) has higher stretch and recovery properties than textured yarn as well as dimensional stability and chlorine resistance along with easy care [14]. PBT is a type of textured polyester filament, and after finishing the process, PBT shows permanent elastic properties [15]. Moreover, dual core-spun yarns have more advantages in terms of yarn stress decay, hairiness, CVm (coefficient of variation of mass), elongation, strength, and durability than core-spun yarns [2, 16]. In addition, compared with conventional ring-spun yarns, dual core-spun yarns show better results in terms of yarn irregularity, hairiness, yarn friction coefficient, yarn tenacity, and elongation [9]. Though filament-based core-spun yarns have higher tenacity than dual core-spun yarn, and elastane draft is proportionally related to the elongation of dual core-spun yarns [17, 18].

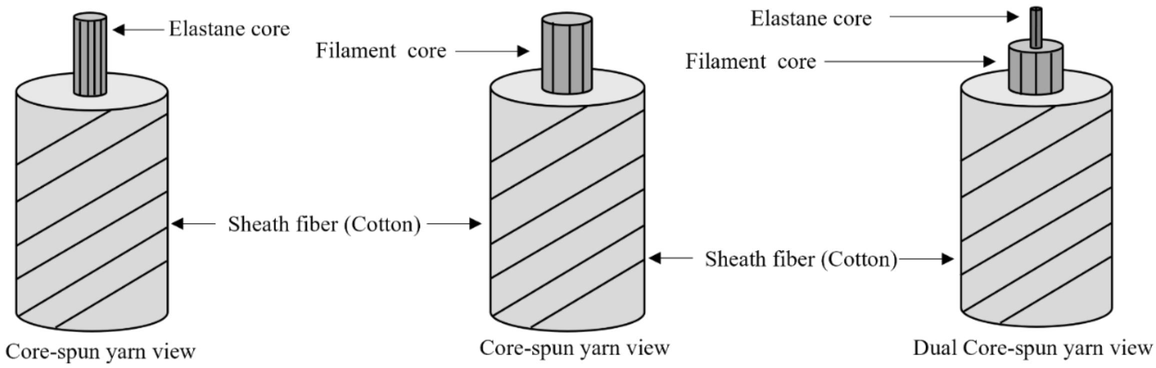

Fig. 1. Illustration of core-spun and dual core-spun yarns view (Picture is drawn by the author)

Core-spun yarn can be produced using a variety of spinning processes, but ring-spinning systems are mostly used [19]. It is found that the production method and feeding system have a statistically significant effect on the yarn properties of the core-spun and dual core-spun yarns [9]. Besides that, core positioning directly affects the core-spun yarn's structure, properties, and performance [20, 21]. Furthermore, it is possible to manufacture finer elastomeric yarn with a more uniform structure and better cover effect [21] and a better cover factor influenced by a higher feed-in angle[22]. These new structured yarns increase not only fabric comfort but also the spinning and weaving process. [1]. Due to having aesthetic properties, these new yarns can be used as a component of the technical textiles field [23] and in smart textiles relying on elasticity [24].

Most of the studies in this area have investigated core-spun yarn properties and its fabrics, while limited work is found on dual core-spun yarn [11, 21, 22, 25]. The limited work found that finer dual core-spun yarns have more unevenness and imperfections but less hairiness and lower tensile properties than coarser ones. Filament linear density showed a significant result on yarn properties [16]. In dual core-spun yarn, tenacity increases with finer core filament, while coarser filament has higher breaking elongation [8]. Regarding fabric width and post-wash change, using dual core-spun yarn shows that fabric construction has more influence than elastic ratio, and adjusting the dual core-spun yarn density on the fabric can produce color variations. Despite having the same elasticity, dual core-spun weft threads had a higher permanent elongation value than regular elastane core-spun weft threads [11]. The dual core-spun yarn count influences the fabric pilling property and the type of yarn used in the dual core-spun yarn [26]. Dual core-spun yarn with elastane shows good elongation and recovery percentage. Increasing the elastane ratio shows a positive relationship with fabric air permeability and extensibility but a negative relationship with fabric tensile strength, dimensional stability, and growth of woven fabrics though weft density has a greater impact on fabric width than the elastane ratio [27]. Elastane filament has extensibility between 300 to 700 %, and 2 to 8 % elastane filament is used in fabrics or yarn [5]. Yarns, having elastane change the fabric properties such as abrasion, strength, extension, and elongation [28]. There is no comparative study using different linear densities and ratios of elastane on different filaments of dual core-spun yarn, as various types of filaments are available in the market. For two different linear densities of yarns, multiple linear densities and ratios of elastane, as well as several types of filaments, such as PTT, PET, and PET/PTT for dual core-spun yarns, were utilized in this study. Yarn properties and fabric properties of those yarns used at the weft direction were analyzed.

2. Materials and methods

For this study, 369.06 dtex (Ne16/1) and 328.06 dtex (Ne18/1) dual core-spun yarns were produced by the modified ring spinning method. Both the filament and elastane were used in the center of the feeding system. Figure 2 represents this study's modified ring-spinning method for producing dual core-spun yarn [16, 29]. 100% Cotton was used as a sheath fiber, and three types of filaments, polyethylene terephthalate/polytrimethylene terephthalate (PET/PTT T400®), polytrimethylene terephthalate (PTT Solotex®) and polyester (PET), were used with two different linear densities for two types of yarns. Here, Lycra® was used as the elastane with three different linear densities such as 44 dtex, 78 dtex, and 117 dtex, along with different amount of ratios to investigate the effect of elastane on the yarn properties as well as denim fabric. Changing the elastane ratio along with the linear density and maintaining the same amount of filament ratio and linear density for 369.06 dtex and 328.06 dtex yarns, a total of eighteen samples of yarn properties were investigated to find out the elastane effects on the dual core-spun yarn with different filaments. From these yarns, 3/1 Z twill weave denim fabrics were also produced where these sample yarns were used as weft yarn, and 421.43 dtex (Ne14/1) indigo dyed 100% cotton yarns were used as the warp yarn with the same linear density of weft yarns. The composition of the weft yarns investigated is shown in Table 1 in detail. For producing these dual core-spun yarns, cotton fiber properties, along with roving properties after cotton fiber processing and filament properties, are shown in Table 2.

Sample	Sheath	Core	Composition	Linear density
DT1	Cotton	55 dtex PET/PTT 44 dtex Elastane	80.45% CO + 15.52% T400® + 4.03% Elastane	328.06 dtex (Ne 18/1)
DS1	Cotton	56 dtex PTT 44 dtex Elastane	80.17% CO + 15.80% Solotex® + 4.03% Elastane	328.06 dtex (Ne 18/1)
DP1	Cotton	55 dtex PET 44 dtex Elastane	80.29% CO + 15.68% PET + 4.03% Elastane	328.06 dtex (Ne 18/1)
CT1	Cotton	83 dtex PET/PTT 44 dtex Elastane	75.60% CO + 20.82% T400® + 3.58% Elastane	369.06 dtex (Ne 16/1)
CS1	Cotton	84 dtex PTT 44 dtex Elastane	75.35% CO + 21.07% Solotex® + 3.58% Elastane	369.06 dtex (Ne 16/1)
CP1	Cotton	83 dtex PET 44 dtex Elastane	75.51% CO + 20.91%PET + 3.58% Elastane	369.06 dtex (Ne 16/1)
DT2	Cotton	55 dtex PET/PTT 78 dtex Elastane	77.91% CO + 15.52% T400® + 6.57% Elastane	328.06 dtex (Ne 18/1)
DS2	Cotton	56 dtex PTT 78 dtex Elastane	77.63% CO + 15.80% Solotex® + 6.57% Elastane	328.06 dtex (Ne 18/1)
DP2	Cotton	55 dtex PET 78 dtex Elastane	77.75% CO + 15.68% PET + 6.57% Elastane	328.06 dtex (Ne 18/1)
CT2	Cotton	83 dtex PET/PTT 78 dtex Elastane	73.34% CO + 20.82% T400® + 5.84% Elastane	369.06 dtex (Ne 16/1)
CS2	Cotton	84 dtex PTT 78 dtex Elastane	73.09% CO + 21.07% Solotex® + 5.84% Elastane	369.06 dtex (Ne 16/1)
CP2	Cotton	83 dtex PET 78 dtex Elastane	73.25% CO + 20.91% PET + 5.84% Elastane	369.06 dtex (Ne 16/1)
DT3	Cotton	55 dtex PET/PTT 117 dtex Elastane	74.63% CO + 15.52% T400® + 9.85% Elastane	328.06 dtex (Ne 18/1)
DS3	Cotton	56 dtex PTT 117 dtex Elastane	74.35% CO + 15.80% Solotex® + 9.85% Elastane	328.06 dtex (Ne 18/1)
DP3	Cotton	55 dtex PET 117 dtex Elastane	74.47% CO + 15.68% PET + 9.85% Elastane	328.06 dtex (Ne 18/1)
CT3	Cotton	83 dtex PET/PTT 117 dtex Elastane	70.43% CO + 20.82% T400® + 8.75% Elastane	369.06 dtex (Ne 16/1)
CS3	Cotton	84 dtex PTT 117 dtex Elastane	70.18% CO + 21.07% Solotex® + 8.75% Elastane	369.06 dtex (Ne 16/1)
CP3	Cotton	83 dtex PET 117 dtex Elastane	70.34% CO + 20.91% PET + 8.75% Elastane	369.06 dtex (Ne 16/1)

Table 1. Structure of composite/hybrid yarns used in this study

Cotton fiber HVI		Roving properties		Filament	Strength, cN/Tex	Elongation%
SCI	140.3	Count Ne	0.7	PET/PTT 55 dtex	35.42	28.54
Mic.	4.98	U%	3.98	PTT 56 dtex	37.75	27.85
UHML (mm)	30.5	CVm%	5.01	PET 55 dtex	44.52	23.50
SFI	6.13	CVm 1m%	1.65	PET/PTT 83 dtex	42.53	26.66
Strength (g/tex)	33.37	CVm 3m%	1.25	PTT 84 dtex	35.36	25.02
Elongation (%)	8.4	CVm 5m%	1.14	PET 83 dtex	40.39	23.73

(SCI – Spinning Consistency Index; Mic. – micronaire; UHML – upper half medium length; SFI – short fiber index; CVm – Coefficient of variation of mass)

Table 2. Properties of cotton fiber, roving, and filaments used in this study

According to the standard method, every yarn sample's strength, unevenness, hairiness, and elongation were measured. For each measurement, five tests were done, and a calculated mean value was used to compare and investigate. The ring machine setting was almost the same for each sample to get a better comparison to produce the dual core-spun yarn with different filaments and elastane linear density. For denim fabric, the weight of the fabric, elasticity, fabric growth, tensile strength, tearing strength, and shrinkage were measured according to the standard method after home washing and conditioning. Table 3 shows the test methods used to measure the yarn and fabric properties. Multiple linear regression analysis was also carried out to find the interaction and develop a quadratic mathematical model between the study's independent and dependent variables using SPSS 25.0. Sometimes, the independent variable is denoted as the predictor variable or regressor and the dependent variable as the response. Here, yarn count, elastane, and filament were

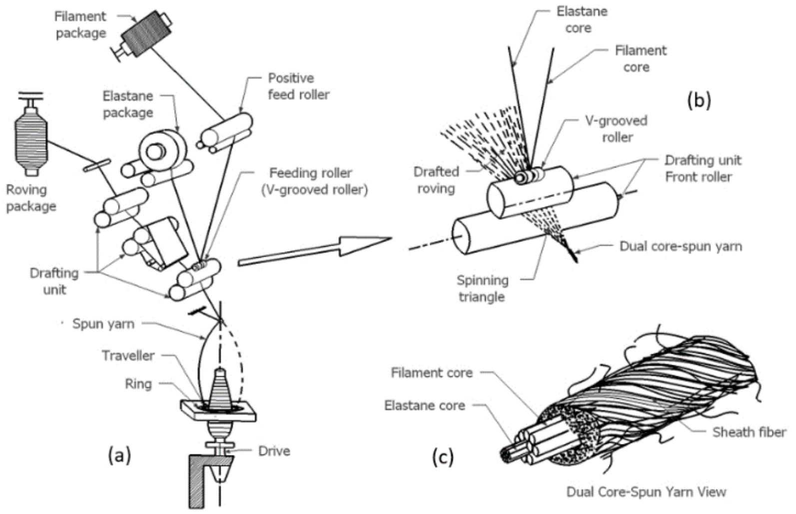

Fig. 2. Schematic illustration of modified ring spinning method for dual core-spun yarn; (a) modified ring spinning arrangement, (b) combination of materials, (c) cross-sectional view of dual core-spun yarn. [16, 29]

Yarn Test	Standard	Fabric test	Standard
Yarn count (dtex)	TS 244 EN ISO 2060	Weight (gsm)	ASTM D3776
Uster unevenness (%)	TS 2394	Tear strength (grf)	ASTM D1424
Yarn hairiness (%)	TS12863	Tensile strength (kgf)	ASTM D5034
Yarn breaking tenacity (%)	TS 245 EN ISO 2062	Shrinkage (%)	AATCC 135
Yarn and fabric sample acceptance and conditioning	ASTM D 1776	Stiffness (kgf)	ASTM D4032
		Elasticity & growth (%)	ASTM D3107

Table 3. Test method standard used in this study for yarn and fabric

considered as independent variables and obtained yarn and denim fabric properties were considered as dependent variables. From the output of the analysis, multiple correlation coefficient R explains the level of prediction, coefficient of determination R^2 indicates how much the independent variables reduced the variability of dependent variables or assesses the model's suitability, and adjusted R^2 is a variant of R^2 that considers the number of predictors in the model. An R^2 value of more than 50% indicates that the mathematical equations obtained from the independent variables have a high predictability of the measured properties. The ANOVA table can explain the significance of the independent variables to predict the dependent variables. A general mathematical equation can be formed from the coefficient table to predict the dependent variables from independent variables [30, 31].

3. Results and discussion

3.1. Yarn properties

3.1.1. Strength

Figure 3 illustrates the strength of different dual core-spun yarns. With 44 dtex elastane, 328.06 dtex (finer) yarn with PTT filament shows slightly higher strength, but 369.06 dtex (coarser) yarn shows the lowest strength, while yarn with PET filament shows the opposite scenario. Yarn with PTT filament having 78 dtex elastane indicates higher strength than others for both yarn linear density. Considering 117 dtex elastane, yarn with PET and PET/PTT filament represents better strength compared to other yarns for finer and coarser yarn, respectively. Overall, coarser dual core-spun yarn samples have more strength than finer yarn samples for all types of filaments and elastane linear density due to their linear density. Within the same linear density of the yarn, having coarser elastane in the core decreases the yarn strength as the amount of sheath fiber is decreased in the yarn's cross-section. It is because the amount of sheath fiber in dual core-spun yarn determines its strength. Similar results were also found in other studies [8, 16]. Moreover, because of the possibility of reduced packing densities for fiber spread out in yarn cross-section, yarn strength decreases as elastane quantity increases. Among all filaments, yarn with PTT filament shows a slighter decrease of strength in terms of increasing elastane coarseness from 44 dtex to 78 dtex. When the elastane linear density is increased from 78 to 117 dtex, it is revealed that yarn with PET/PTT filament has less strength loss, while overall yarn with PET filament and PTT filament has less strength loss for finer and coarser yarns, respectively. The strength loss of the yarn for different filaments can be affected by the filament's surface features in dual core-spun yarns, as well as the packing density of the yarn.

A multiple regression analysis was run to predict the yarn strength from yarn count, elastane, and filament-independent variables. From Table 4, the model summary of the analysis shows a value of R=0.764, which indicates a good prediction level. Here, R^2= 0.584 shows that independent variables can explain 58.4% of the variability of the yarn strength. Table 4 also shows that F (3,86) = 40.287 and P<0.05, which illustrates that independent variables are statistically significantly useful in predicting yarn strength. From the coefficient Table 5, a regression equation (1) is obtained for yarn strength.

Yarn strength = 24.098 – 0.549 yarn count – 0.019 elastane – 0.025 filament (1)

From the significance column in Table 5, it is found that yarn count and elastane have a statistically significant effect, $p < 0.05$, while the change in the filament type is not statistically significant on yarn strength.

3.1.2. Elongation

Figure 4 illustrates the elongation of different dual core-spun yarns. The elastane 44 dtex, yarns with PET filament have less elongation for both linear densities than other yarns. Yarn with PTT filament shows high elongation for the finer sample, but coarser sample yarn with PET/PTT filament shows high elongation compared to others. Containing 78 dtex and 117 dtex elastane in the core shows that yarns with PET filament have less elongation than others. A content of PTT filament in the core of the yarns shows higher elongation. The whole picture shows that yarns with PTT filament have high elongation while those with PET filament exhibits lower elongation, where the finer yarn has less elongation than the coarser yarn of that filament. Moreover, increasing the elastane coarseness of the dual core-spun yarns increases elongation in the case of a higher amount of elastane in the core, as the ratio or amount of elastane affects yarn elongation [8]. Therefore, yarn linear density, filament type, and elastane ratio are the parameters for determining dual core-spun yarn's elongation.

From Table 4 presenting a multiple regression model summary for yarn elongation, it is found that $R^2 = 0.593$, which means a 59.3% change in the yarn elongation can be explained by the dependent variables. From ANOVA Table 4, for yarn elongation, $F(3,86) = 41.836$, and $P < 0.05$, which illustrates that independent variables are statistically significantly useful for predicting yarn elongation. The regression coefficient in Table 5 shows that elastane and filament type change is statistically significant, while the other variable, yarn count, is not. The regression equation (2) obtained for yarn elongation is given below.

Elongation% = 9.357 + 0.0.20 yarn count + 0.030 elastane – 0.679 filament (2)

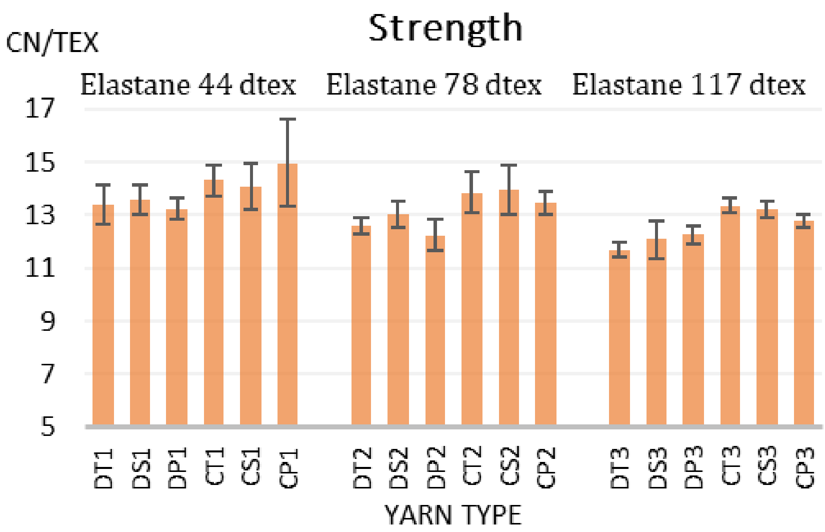

Fig. 3. Strength of dual core-spun yarns

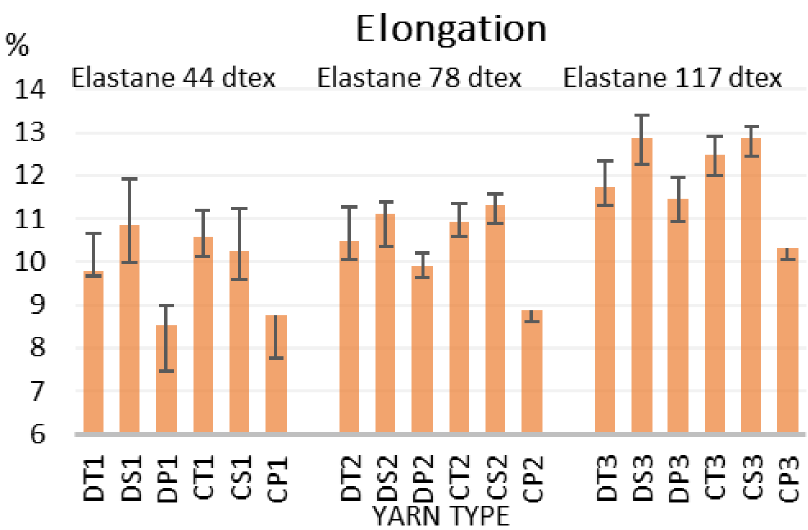

Fig. 4. Elongation% of dual core-spun yarns

3.1.3. Unevenness

Figure 5 shows that finer dual core-spun yarn samples have more unevenness% than the coarser yarn samples as the amount of sheath fiber determines the yarn unevenness [16]. Here, for 44 dtex elastane, yarn with PTT filament shows higher unevenness comparing to others. Increasing elastane linear density to 78 dtex, it is found that PET filament with coarser yarn sample shows less irregularity but higher with the finer yarn and for 117 dtex elastane, the figure indicates that for both yarn linear density samples, PET shows the highest unevenness% than others where yarn with PET/PTT filaments have the lowest. Overall, it shows that yarns with elastane 44 dtex have a high unevenness% and yarns with 117 dtex elastane have a low unevenness% as the amount of sheath fiber is reduced though there is no regular change for elastane increasing. The filament yarn's bulkiness features are most likely responsible for this scenario [32]. The presence of a dual core in the cross-section also impacts yarn irregularity due to the uneven spread of sheath fiber. Unevenness is significantly changed along with yarn linear density for PET filament, where PET/PTT filament shows minor change. Having the same linear density, yarn with PET filament shows a slighter decrease of unevenness% for the coarser sample,

Model Summary					ANOVA		
Dependent Variables	R	R Square	Adjusted R Square	Std. error of the Estimate	Dependent variables	F	Sig.
Strength	0.764	0.584	0.570	0.67503	Yarn Strength	40.287	0.000
Elongation	0.770	0.593	0.579	0.88906	Yarn elongation	41.836	0.000
Unevenness	0.649	0.421	0.401	0.43800	Yarn Unevenness	20.846	0.000
Hairiness	0.605	0.366	0.344	0.56914	Yarn Hairiness	16.526	0.000

Table 4. Regression model and ANOVA table for yarn properties

where unevenness% is increased for the finer sample.

From the regression model summary in Table 4, the $R^2 = 0.421$ means that 42.1% change in the unevenness can be explained by the independent variables. From the ANOVA Table 4, for yarn unevenness, it is found that F (3,86) = 20.846 and P <0.05, which illustrates that the group of independent variables is statistically significant and can be used to predict yarn unevenness reliably. From the regression coefficient in Table 5, it can be said that the change in yarn count and elastane are statistically significant, while the other variable, such as filament type, is not statistically significant for yarn unevenness. A regression equation (3) obtained for yarn unevenness is given below,

Unevenness = 6.204 + 0.303 yarn count – 0.006 elastane + 0.116 filament **(3)**

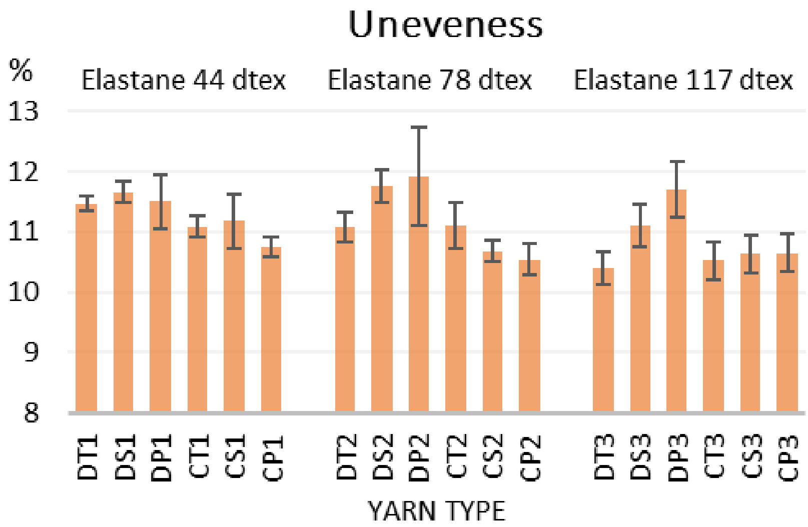

Fig. 5. Unevenness% of dual core-spun yarns

3.1.4. Hairiness

The hairiness of yarn samples with different elastane linear densities is shown in Figure 6, indicating no regular change in terms of yarn linear density. Having 44 dtex elastane shows that coarser yarns have almost the same and higher amount of hairiness than finer yarn samples. Yarn with PTT filament shows less hairiness with finer yarn but a high amount of hairiness with coarser yarn samples, which is increased by about 30%. For 78 dtex elastane, yarn with PTT filament shows more hairiness on its surface for finer samples but less hairiness for coarser yarn samples, whereas yarn with PET/PTT filament shows opposite results. Coarser yarns with 44 dtex and 117 dtex elastane have higher hairiness than finer yarns for all filaments, except for yarn with 78 dtex elastane. Thus, there is no regular relation between yarn type and hairiness in terms of elastane change. Almost every sample shows a lower amount of hairiness with 117 dtex elastane than samples with 44 dtex elastane except yarn with PTT filament, where hairiness is increased. As the number of short-staple sheath fibers decreases to have a higher amount of elastane, the amount of protruding fiber decreases, and therefore hairiness decreases. Also, the surface characteristics of the different filaments and their interaction with other components have an effect on yarn hairiness.

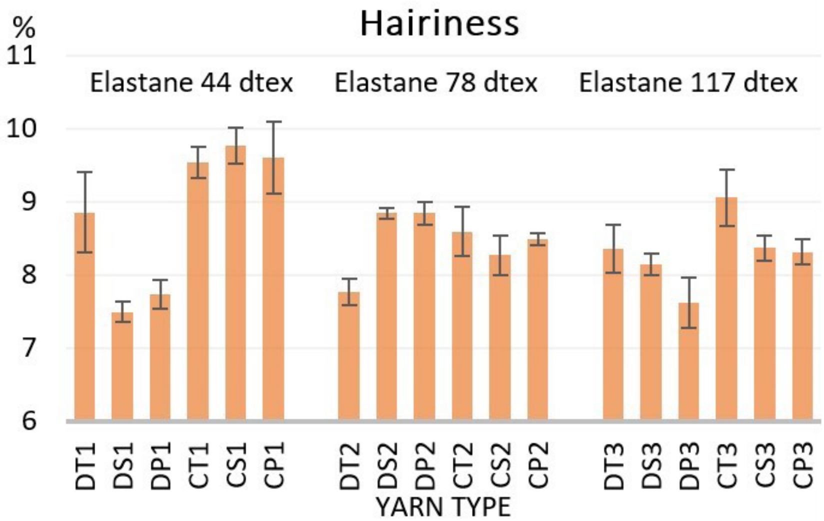

Fig. 6. Hairiness% of dual core-spun yarns

Coefficient								
	Strength		Elongation		Unevenness		Hairiness	
Terms	Coefficient	Sig.	Coefficient	Sig.	Coefficient	Sig.	Coefficient	Sig.
Constant	24.098	0.000	9.357	0.000	6.204	0.000	15.286	0.000
Yarn count	-0.549	0.000	0.020	0.828	0.303	0.000	-0.348	0.000
Elastane fineness	-0.019	0.000	0.030	0.000	-0.006	0.000	-0.007	0.001
Filament type	-0.025	0.776	-0.679	0.000	0.116	0.044	-0.127	0.087

Table 5. Regression coefficients for yarn properties response variables using values of the independent variables

From the multiple regression analysis (Table 4) for yarn hairiness, it is found that R^2 =0.366, which indicates that only 36.6% variance in the yarn hairiness can be predicted from the independent variable though the ANOVA (Table 4) shows F (3,86) = 16.526, and p < 0.000, which means that independent variables can be used to predict the yarn hairiness reliably, from Table 4. A regression equation (4) for yarn hairiness can be developed from the obtained coefficient value of Table 5, and from the significance column, it is found that the change in yarn count and elastane is statistically significant, while the change in filament type is not statistically significant.

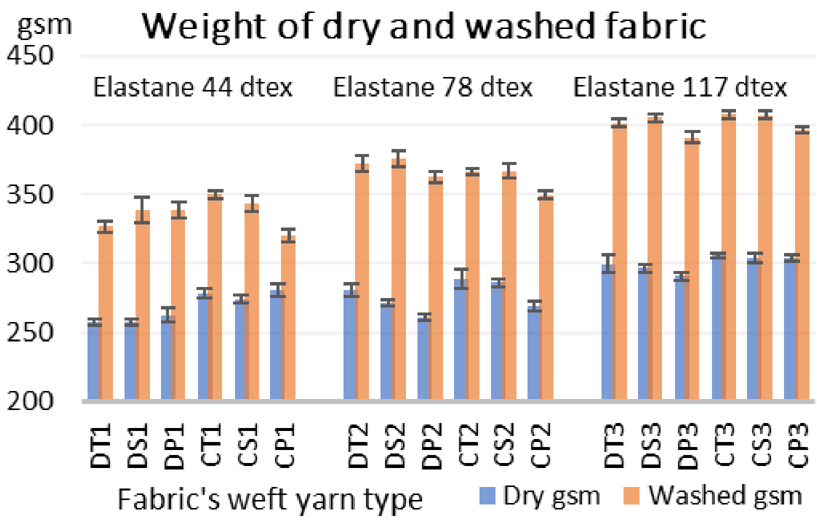

Fig. 7. Weight of dry and washed fabrics

Yarn hairiness = 15.286 - 0.348 yarn count – 0.007 elastane - 0.127 filament **(4)**

4. Fabric properties

4.1. Dry and washed weight of fabrics

Figure 7 shows that increasing the elastane coarseness increases the fabric's dry and washed gsm (gram per square meter) though having the same yarn linear density. It also indicates that the change of fabric gsm from dry to washed increases with elastane coarseness. Fabrics with finer elastane have a reduced amount of changes in gsm percentage after washing. For elastane 44 dtex, except the CP1 sample, other samples have more than 25% increase of gsm, and for elastane 78 dtex, all the samples have more than 28% increase of gsm, whereas DP2 and DS2 samples show a slightly higher than 38% increase. Most of the time, fabric with PTT weft yarn shows a higher increase in gsm percentage after washing than fabric with PET and PET/PTT filament yarns with an elastane change. Fabric with 117 dtex elastane shows more than 30% gsm increase for both yarns counts from dry to washed. As the amount of elastane percentage and linear density increases, the compactness of the fabric also increases due to its elastic properties. For this reason, the number of weft and warp yarns in a square meter is also increased, which denotes shrinkage or dimensional changes in the fabric. Therefore, after washing, the shrinkage or dimensional changes of the fabric help to increase its gsm. Within the same filament, after washing, the change of gsm percentage is increased while increasing the elastane dtex for the coarser weft yarn specimen, but no such scenario is found for the finer weft yarn specimen.

The model summary of fabric properties multiple regression in Table 6 shows that the value of R^2 for fabric dry and washed weight is 0.825 and 0.921, respectively. Here, the independent variables can explain 82.5% and 92.1% of fabric dry and washed weight variability, respectively. Independent variables are also statistically significant in predicting the fabric weight, as found in the ANOVA in Table 7. From the coefficient in Table 8, it is found that all the independent factors are statistically significant for fabric dry and washed weight except yarn count for the washed weight of the fabric. The regression equations (5 and 6) obtained for fabric dry and washed weight are given below,

Fabric dry weight = 360.75 – 6.289 yarn count + 0.438 elastane – 3.517 filament (5)

Fabric washed weight = 302.034 + 0.311 yarn count + 0.899 elastane – 5.55 filament (6)

4.2. Elasticity and growth properties

Figure 8 illustrates the elasticity% of different fabric samples and indicates that elastane linear density impacts the elasticity of the fabric. Having high elastane dtex in the dual core-spun yarns increases the fabric elasticity, and fabrics from finer yarn samples have more elasticity than fabrics from coarser yarn samples as a finer yarn has less sheath fiber than the coarser ones. While increasing the amount of elastane along with coarseness, yarn samples containing PET filament show more changes of elasticity% than others though that yarn has less amount of elongation. For different elastanes and different linear densities, filaments show no regularity of elasticity%. The elastic properties of the elastane influence the fabric's elastic properties and almost all filaments have more or less the same amount of elongation individually; that is why fiber and filament arrangement in the weft yarn gives a variable elasticity of the fabrics.

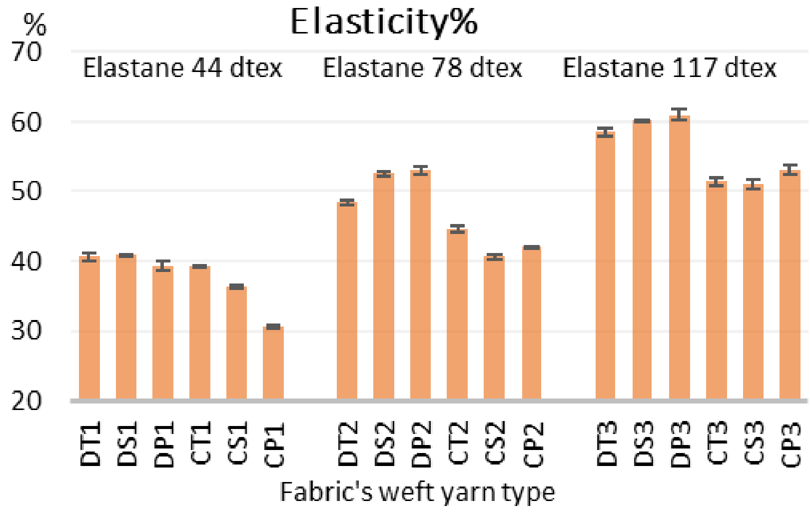

Fig. 8. Elasticity% of the fabrics

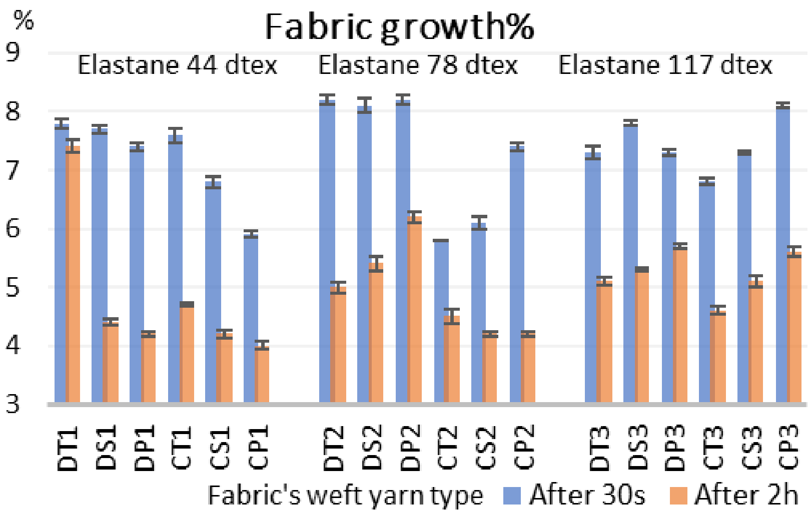

Fig. 9. Growth% of the fabric

The growth% of fabric samples are given in Figure 9. Fabric with finer yarn has more growth than a coarser yarn with specific filaments. Fabrics having 44 dtex elastane and PET/PTT filament in their weft yarn have higher growth % both in 30 seconds and 2 hours. At 2 hours, with 117 dtex elastane, fabric with PET filament shows the highest growth%, and almost every sample has more than 5% growth except the sample with 369.06 dtex weft yarn with PET/PTT filament. Whereas yarn samples with 44 dtex elastane have less than 5% fabric growth. Overall, there is no regular trend found to give a conclusion due to changes in elastane amount and linear density, but for 117 dtex elastane, there is a stable picture found for growth%. Using different filaments with different ratios of elastane in the weft yarns influences the growth% of the fabrics, and their combination with the arrangement in the yarn also affects the result.

From the multiple regression model summary in Table 6, the R^2 value of elasticity and growth properties of the fabric at 30 seconds and 2 hours is 0.938, 0.381, and 0.305, respectively, which denotes that independent variables can explain 93.8%, 38.1%, and 30.5% variability of the fabric elasticity, fabric growth properties at 30 seconds and 2 hours, respectively. From the ANOVA in Table 7 of regression analysis, it is found that independent variables are statistically significant for predicting fabric elasticity and growth properties. From the coefficient Table 8, it is found that change of filament type has no significance for fabric elasticity and growth properties while all other independent variables have significance except elastane for fabric growth at 30 seconds. The regression equations (7-9) for elasticity and growth properties are given below.

$$\text{Fabric elasticity} = -33.99 + 3.639 \text{ yarn count} + 0.247 \text{ elastane} - 0.342 \text{ filament} \quad (7)$$

$$\text{Fabric growth\% 30s} = -0.633 + 0.444 \text{ yarn count} + 0.003 \text{ elastane} - 0.067 \text{ filament} \quad (8)$$

$$\text{Fabric growth\% 2hr} = -2.415 + 0.422 \text{ yarn count} + 0.006 \text{ elastane} - 0.117 \text{ filament} \quad (9)$$

4.3. Fabric strength

In this study fabric's tensile and tearing strength were evaluated for both directions of the fabric. Figure 10 shows fabric tensile strength for different yarn samples in warp and weft directions. As dual core-spun yarns are used in the weft direction, the fabric's weft tensile strength is only considered. It is found that fabrics with coarser yarn samples have more tensile strength than finer ones. For the PET/PTT sample, increasing the elastane dtex first decreases the fabric tensile strength and then increases it, while for the PTT sample's tensile strength first increases and then decreases for both yarn linear density and for the PET sample, no predictability could be shown. Overall, it is indicated that there is no regular change of tensile strength in the weft direction for the specific filament of both finer and coarser yarn samples in terms of changing elastane linear density. For finer yarn samples, fabric with PTT filament shows the highest tensile strength, and for coarser yarn samples, fabric with PET shows the highest tensile strength at any of elastane's linear density. No clear trend was also found for the tensile properties of the fabric regarding yarn count and core filament linear density [8].

As sample yarns are used here only in the weft direction of the fabric, the tearing strength in the weft direction is considered to evaluate the fabric samples. Figure 11 shows that coarser yarn fabrics have higher tearing strength in the weft direction than finer yarn fabric. Although finer yarn samples do not show any regularity on elastane change, the coarser yarn sample's tearing strength is first increased and then decreased with the increase of elastane dtex for each sample. For coarser yarn fabric, the PET sample has higher, and the PTT sample has lower tearing strength, respectively, while finer yarn samples do not have such an indication. However, no trend was found in the strength of the filament regarding different dtex values that affect the strength level of the yarns and fabrics. Core filaments surface coating, interaction with sheath fiber, and elastane may change the arrangement of the core filament, which possible displacement may cause the irregularity of yarn and fabric strength level.

From the multiple regression model summary in Table 6, it is found that the value of R^2 for warp and weft tensile strength and for warp and weft tearing strength are 0.797, 0.914, 0.733, and 0.795, respectively, which denotes that independent variables can explain 79.7%, 91.4%, 73.3% and 79.5% variability of warp and weft tensile strength and warp and weft tearing strength respectively. Table 7 also shows that the independent variables can be used to predict the fabric tensile and tearing strength reliably. The regression coefficient Table 8 represents that warp tensile strength, weft tensile strength, warp tearing strength, and weft tearing strength is not statistically significant for the yarn count, elastane, filament type, and elastane, respectively, while others have significance. Obtained regression equations (10-13) are given below for fabric strength.

Model Summary				
Dependent Variables	**R**	**R Square**	**Adjusted R Square**	**Std. Error**
Fabric dry weight	0.908	0.825	0.818	6.97576
Fabric washed weight	0.959	0.921	0.918	8.17244
Fabric elasticity	0.968	0.938	0.935	2.16641
Fabric growth% 30 sec	0.617	0.381	0.359	0.59702
Fabric growth% 2hr	0.552	0.305	0.280	0.72006
Warp tensile strength	0.892	0.797	0.789	2.53191
Weft tensile strength	0.956	0.914	0.911	1.29636
Warp tearing strength	0.856	0.733	0.724	49.19050
Weft tearing strength	0.891	0.795	0.788	182.10435
Warp shrinkage	0.444	0.197	0.169	1.72689
Weft shrinkage	0.845	0.714	0.704	2.07561
Stiffness	0.919	0.844	0.839	0.06412

Table 6. Regression analysis model summary for fabric properties

ANOVA					
Dependent variables	**F**	**Sig.**	**Dependent variables**	**F**	**Sig.**
Fabric dry weight	134.749	0.000	Warp tensile strength	112.240	0.000
Fabric washed weight	332.405	0.000	Weft tensile strength	303.867	0.000
Fabric elasticity	431.107	0.000	Warp tearing strength	78.768	0.000
Fabric growth% 30s	17.643	0.000	Weft tearing strength	110.975	0.000
Fabric growth% 2 hr	12.552	0.000	Warp shrinkage	7.052	0.000
Stiffness	155.364	0.000	Weft shrinkage	71.492	0.000

Table 7. ANOVA table for fabric properties of regression analysis

$$\text{Warp tensile strength} = 71.33 + 0.1\ \text{yarn count} + 0.16\ \text{elastane} - 1.383\ \text{filament} \quad (10)$$

$$\text{Weft tensile strength} = 104.2 - 4.11\ \text{yarn count} + 0.002\ \text{elastane} - 0.417\ \text{filament} \quad (11)$$

$$\text{Warp tearing strength} = 4324.973 + 26.783\ \text{yarn count} + 2.5\ \text{elastane} + 10.8\ \text{filament} \quad (12)$$

$$\text{Weft tearing strength} = 9024.065 - 331.289\ \text{yarn count} + 0.049\ \text{elastane} - 139.20\ \text{filament} \quad (13)$$

4.4. Fabric shrinkage

Figure 12 represents the fabric shrinkage percentage in the warp and weft direction. As yarn samples are used in the weft direction of the fabrics here, only weft shrinkage is considered. It is found that finer yarn fabrics samples show higher shrinkage than coarser yarn samples, and with the increase of elastane dtex, fabric shrinkage is increased. The elastic properties of elastane are the reason behind it. Increasing the linear density of elastane from 44 dtex to 78 dtex, it is found that PET samples show the highest increase in shrinkage percentage

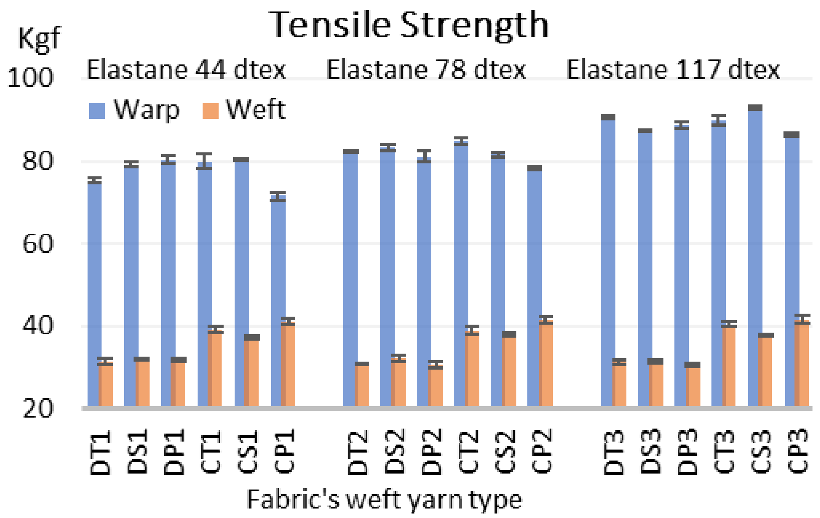

Fig. 10. Warp and weft tensile strength (kgf) of the fabrics

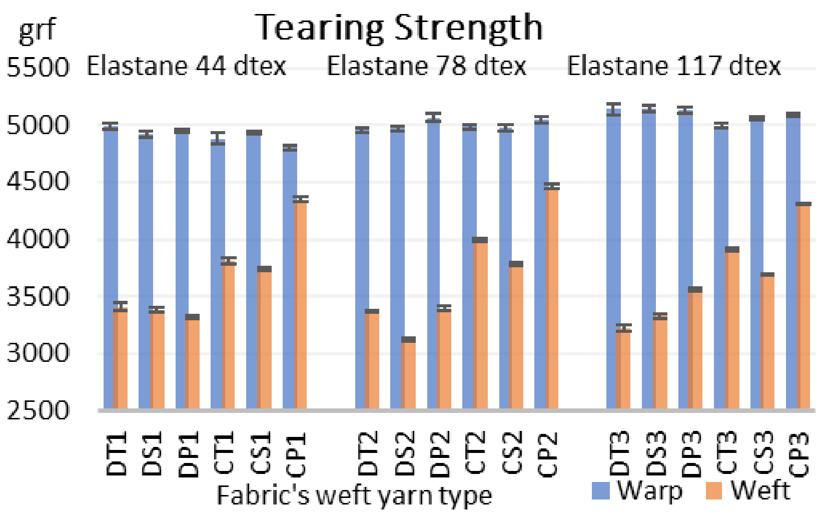

Fig. 11. Warp and weft tearing strength (grf) of the fabrics

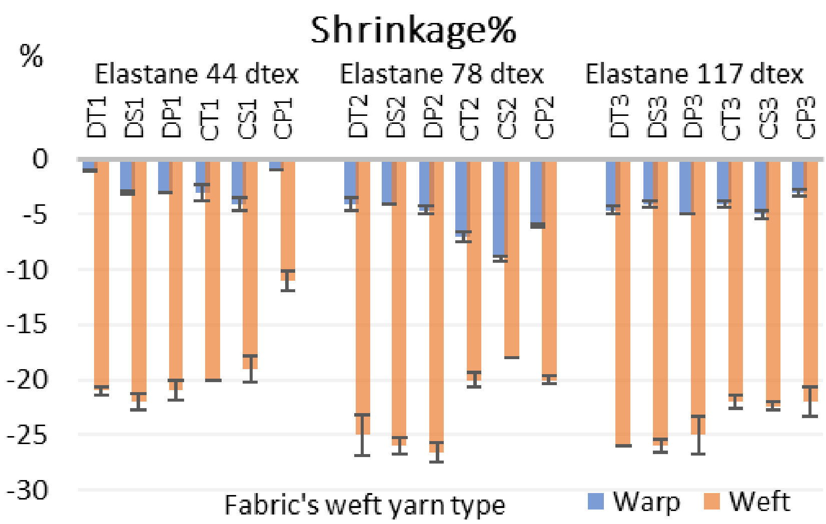

Fig. 12. Warp and weft shrinkage% of the fabrics

but cannot maintain it further, and there is no regularity for specific filament. For 44 dtex elastane, the PTT and PET/PTT samples have higher shrinkage for finer and coarser yarn fabric. Fabrics containing 78 dtex elastane and PET filament yarn in their weft direction have higher shrinkage than others for both yarn linear densities. However, for 117 dtex elastane, yarn with PTT filament has a higher shrinkage percentage. Figure 12 shows that warp side shrinkage increases gradually with high elastane dtex in the weft yarn. From the model summary of regression analysis in Table 6, it is found that the value of R^2 for warp and weft shrinkage of the fabric is 0.197 and 0.714, respectively, which shows that the independent variables can explain 19.7% and 71.4% shrinkage change of warp and weft direction. Table 7 represents those independent variables that are statistically significantly useful to predict fabric shrinkage in both directions. The only change of filament type has no significant effect on warp shrinkage of the fabric, while others have significance in both directions, as found in Table 8. The regression equations (14, 15) obtained for shrinkage are given below.

$$\text{Fabric warp shrinkage} = -10.849 + 0.489\ \text{yarn count} - 0.023\ \text{elastane} + 0.083\ \text{filament} \tag{14}$$

$$\text{Fabric weft shrinkage} = 23.793 - 2.456\ \text{yarn count} - 0.066\ \text{elastane} + 0.7\ \text{filament} \tag{15}$$

4.5. Stiffness

Figure 13 shows that by increasing the elastane amount and coarseness in the dual core-spun yarn, fabric stiffness% is increased with the same filament and yarn linear density. Generally, fabrics with coarser yarns have more stiffness than finer ones. Due to high elastane content, there is an increase in dimensional changes, resulting in more compact fabric and making it stiffer. Fabric having 44 dtex elastane and PTT filament shows higher stiffness for finer yarn samples and lesser for coarser yarn samples, whereas

Dependent variable		constant	yarn count	elastane	filament
Fabric dry weight	coefficient	360.750	-6.289	0.438	-3.517
	significance	0.000	0.000	0.000	0.000
Fabric washed weight	coefficient	302.034	0.311	0.899	-5.550
	significance	0.000	0.719	0.000	0.000
Fabric elasticity	coefficient	-33.990	3.639	0.247	-0.342
	significance	0.000	0.000	0.000	0.225
Fabric growth% 30s	coefficient	-0.633	0.444	0.003	0.067
	significance	0.565	0.000	0.133	0.389
Fabric growth% 2 hr	coefficient	-2.415	0.422	0.006	-0.117
	significance	0.071	0.000	0.026	0.213
Warp tensile strength	coefficient	71.330	0.100	0.160	-1.383
	significance	0.000	0.709	0.000	0.000
Weft tensile strength	coefficient	104.200	-4.111	0.002	0.417
	significance	0.000	0.000	0.606	0.015
Warp tearing strength	coefficient	4324.973	26.783	2.500	10.800
	significance	0.000	0.000	0.000	0.093
Weft tearing strength	coefficient	9024.065	-331.289	0.049	139.200
	significance	0.000	0.000	0.940	0.000
Warp shrinkage	coefficient	-10.849	0.489	-0.023	0.083
	significance	0.001	0.009	0.000	0.709
Weft shrinkage	coefficient	23.793	-2.456	-0.066	0.700
	significance	0.000	0.000	0.000	0.011
Stiffness	coefficient	0.306	0.006	0.005	-0.033
	significance	0.011	0.413	0.000	0.000

Table 8. Regression coefficients for fabric properties response variables using values of the independent variables

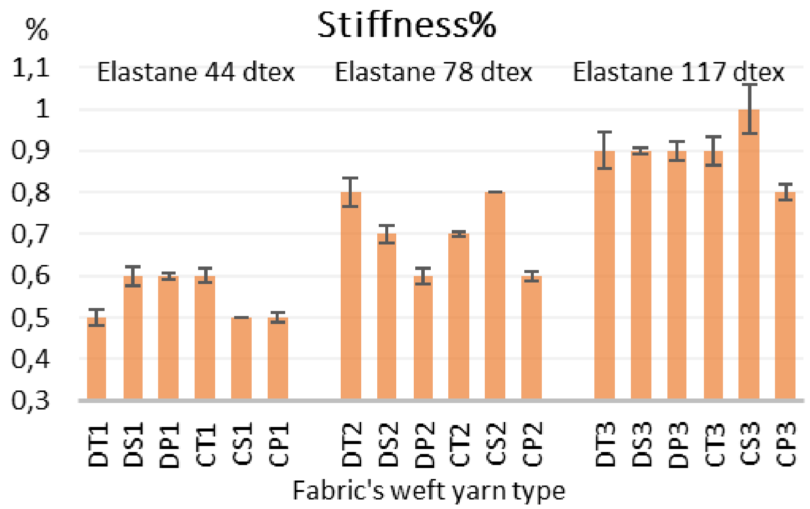

Fig. 13. Stiffness of the fabrics

fabric with PET filament shows the opposite trend. For 78 dtex and 117 dtex elastane, fabrics having PET filament in its weft direction have less stiffness than others, whereas, among the three filaments, fabric with yarn having PTT filament shows almost high stiffness as the yarn with PTT filament has higher elongation% which helps to make the fabric more compact, resulting higher stiffness than others.

From Table 6, it is shown that the value of R^2 is 0.844, which means independent variables can explain the 84.4% variability of the fabric stiffness. From Table 7, it can be said that all the independent variables affect fabric stiffness. Table 8 shows that yarn count has no statistical significance for stiffness, while other variables have significance. The regression equation (16) for stiffness is given below.

$$\text{Stiffness} = 0.306 + 0.066\ \text{yarn count} + 0.005\ \text{elastane} - 0.033\ \text{filament} \tag{16}$$

5. Conclusion

The main focus of this study was finding the effect of elastane linear density on different filament types of dual core-spun yarn and fabric made of it. Mathematical equations were developed from the regression analysis, and the effect of independent variables was examined. It was found that independent variables were statistically significant in predicting the dependent variables.

The study's findings are that using different elastane linear densities in the dual core-spun yarn has a common effect on yarn strength and elongation.

While increasing the elastane linear density, yarn strength increases, while the elongation of yarn decreases. Moreover, for yarn samples with 44 dtex elastane and 117 dtex elastane, unevenness is high, and hairiness is low, respectively. However, having coarser elastane in the dual core-spun yarns means high stiffness, elasticity, and shrinkage for fabric. Furthermore, with the same yarn linear density, the coarser elastane affects the dry and washed weight of the fabric.

It is also found that dual core-spun yarn with PET/PTT filament has more hairiness and minor change in unevenness, and PTT filament has higher elongation and a slighter decrease of strength with elastane change. Finer yarn with PET filament has higher but less unevenness and elongation with coarser yarn. The PET sample showed a significant change in unevenness with respect to yarn linear density. From the observation of fabric properties, it was concluded that fabric with PTT filament in its weft yarn has a high weight change after washing. Moreover, the fabric sample with PTT filament shows high stiffness, whereas the fabric sample with PET has low stiffness. A coarser PET sample has a higher tearing and tensile strength.

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Declaration of conflicting interests

The authors declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article

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