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Investigating the effect of different filaments and yarn structures on mechanical and physical properties of dual-core elastane composite yarns

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ABSTRACT

Dual-core yarns, containing two filaments within the core of the yarn, have gained increasing commercial and research interest recently, especially in denim manufacturing. The use of multi-components in dual-core yarns allows for tailoring the properties of the yarn and denim fabric. The type of filaments and fibers and their surface characteristics play a role in fiber-to-fiber cohesion within yarn structure. However, little has been reported regarding the effect of different filaments on the properties of dual-core yarns. The objective of this study was to investigate the effect of three different filaments, T400, polyester flat (PET flat) and polyester textured (PET textured) as well as two yarn structures, siro versus non-siro, on tensile, elastic and other properties of dual-core yarns at same twist level and linear density of the yarn. The results showed that the siro spun dual-core yarn containing T400 exhibited 25% higher tenacity compared with yarns containing other filaments. However, the plastic deformation of the yarn containing PET flat filament, having a higher initial modulus, was at a relatively lower level compared with T400 and PET textured. Overall, the siro yarn structure showed lower imperfections and higher tenacity compared with the non-siro yarn structure. The dual-core yarn containing T400 showed a higher level of moisture wicking compared with other filaments which can add to the comfort properties but a similar hairiness level. The findings of this study suggest that the use of a filament with a higher initial modulus can improve the stretch and recovery behavior of the dual-core yarns.

1. Introduction

Stretchable yarns are being increasingly used in different types of apparel and clothing products such as sportswear, swimwear,

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compression stockings and especially in stretchable denim [1–3]. When made of stretchable denim fabrics, denim provides superior performance in terms of stretch, fit, ease of body movement and overall comfort of the wearer. Even simple body movements such as bending of knees may stretch the fabric causing stress on the skin from 20 to 45% [4]. The closer the fabric is to the skin, the more it will be stretched imposing a higher level of stress on the skin as is the case of denim pants. Therefore, core-spun elastane yarns are used in the weft direction of the denim fabric to make the denim stretchable.

As sheath fiber, either cotton or a blend of cotton with synthetic fibers usually polyester is used. The cotton fibers are blended with polyester fibers to enhance the comfort level associated with the high absorbency and feel of the cotton fibers [5]. The use of core-spun elastane yarn containing stretchable elastane filament within the core of the yarn gives stretchability to the stretch fabrics [6,7]. However, single-core yarns may have poor dimensional stability and aging resistance and, therefore, get loose giving a bagging effect. This will result in poor body movement comfort. In some applications, such as workwear, this may even be a safety concern. Therefore, researchers have investigated the reliability of stretchable workwear under abrasive load [8]. Dual-core yarns have been developed to take advantage of the individual properties of each of the component filaments and fibers of the yarns.

In core-spun yarns, elastane filaments provide stretch and recovery properties and sheath fibers provide aesthetic and comfort to the yarn and products made of it [9]. Elastane filaments are available commercially under different brand names such as Lycra, Creora and Dorlastan. Elastane filaments are made of polyurethanes and have complex structures [10]. In dual-core yarns, the use of a second filament in the core can provide support to dimensional stability and is useful to take advantage of the properties of different individual components [11]. The plastic deformation of the dual-core yarn is reported to be lower than conventional ring-spun and single-core yarns [9,12]. Thus, each component of a dual-core yarn can render a unique property to the yarn and fabric made of it. Core-spun yarns can be prepared on conventional ring-spinning frames with additional attachments on the ring frame for each core filament [13]. It is expected that dual-core yarns perform better than single-core yarns and can help meet the demand for increased strength and elasticity of denim fabric [11].

The stretch and recovery properties of the elastane yarns are dependent on several factors such as elastane percentage in the yarn [14], elastane draft and elastane linear density [6,12], yarn structure [5,15], the position of the filament within the core [16], presence of single or dual-core filaments [17], process parameters [18], and the filament itself. Although the interest in dual-core yarns has increased, fewer research studies have explored the properties of different dual-core yarns [17].

In dual-core yarns, commercially available T400 polyester filament is used along with elastane filament in the stretch yarns. T400 is known to have good elasticity due to its bicomponent structure composed of 3-GT type polyester and 2-GT type polyester in the ratio 40:60. The bicomponent nature of T400 gives it regular crimp when exposed to heat giving it crimped or coiled structure and thus rendering it with good elastic properties to be used in stretch yarns [9]. It is ranked between textured filaments and lycra due to its stretch and recovery properties [15]. The properties of the yarn and end products made of it are dependent on the mechanical and other properties of individual fiber components used in the yarn [19].

In addition, the cohesion among different component fibers in the yarn strongly influences the mechanical properties of the yarn [20]. In the case of dual-core yarns, cohesion among sheath fibers and core and sheath fibers is important and can increase or decrease the breaking load and extension of the yarns [9]. In core-spun yarns, the slippage of sheath fibers on core filaments is a common problem that can be controlled using different yarn structures [21]. Siro-spun yarns are reported to exhibit improved mechanical and physical properties compared with simple ring-spun non-siro yarns [20,22–25]. Siro yarn structures have been found to release relatively fewer fibers during washing and abrasive wear [26]. The surface characteristics of fibers and filaments can also influence fiber cohesion. The cohesion among fibers is high if the surface is rough and has crimps or any other form of texturization. Synthetic filaments are available in various forms [27]. However, the effect of different filaments having different surface characteristics as well as yarn structures has not been thoroughly investigated on single or dual-core yarns.

Therefore, the objective of this study was to investigate the effect of different polyester filaments having different surface characteristics as well as different yarn structures on the properties of dual-core elastane yarns. To the best of our knowledge, such an investigation has not yet been reported in the literature. In particular, tensile, stretch and recovery properties under cyclic loading were investigated. Three different filaments include the commercially available T400, polyester filament flat (denoted as PET flat in this study) having a smooth surface without any texturization and polyester filament textured (denoted as PET textured) having a crimped surface. In addition, the effect of two yarn structures, namely siro versus non-siro ring-spun, was also investigated. A 60:40 blend of polyester and cotton fibers was used as sheath fibers.

2. Materials and methods

2.1. Materials

In this study, dual-core cotton/polyester blended yarns were produced. The sheath fibers were composed of a polyester/cotton blend in a blend ratio of 60:40 where Pakistani cotton was used in the blend. The properties of Pakistani cotton fibers, measured using

Table 1
Properties of Pakistani cotton used in this study.

Material	Mic (μg/inch)	UI %	SF %	Tenacity (Breaking Strength) (g/tex)	Breaking Elongation (%)
Pakistani cotton	4.5	86	3.8	41.5	6.5

the Uster HVI instrument, and polyester fibers used in the sheath, as provided by the manufacturer, used in the Polyester/cotton blend are given in Table 1 and Table 2 respectively. In Table 1, Mic represents the fineness of the fibers measured in micrograms per inch, UI % stands for uniformity index representing how uniform fibers are, SF % represents the short fiber index of the fibers, tenacity represents the breaking strength of the fibers measured as gram force per tex of the fiber and breaking elongation represents elongation at break when fibers were tested using HVI instrument. Table 2 represents The linear density of the elastane monofilament was 70 D whereas the linear density of T400, PET flat and PET textured multifilaments was 75 D. The dual-core yarns contained three different filaments: commercially available T400 multifilament, polyester filaments with flat or smooth surface (PET flat) and polyester filaments with textured surface (PET textured).

2.2. Preparation of yarns

In this study, single and dual-core siro and non-siro yarns were prepared on a lab-scale mini-ring frame equipped with two attachments: one for elastane filament and the other one for second filament. Single yarns were prepared for comparison purposes. The six dual-core siro and non-siro yarns contained dual filaments within the core while two single-core siro and non-siro yarns contained elastane filaments only. The details of the eight samples along with their abbreviations used in this study are given in Table 3.

The yarn samples of 10 Ne (59 Tex) were produced from hank roving of 0.68 Ne (868Tex) at the same twist level with a twist multiplier twist multiplier (TM) of 5.0 resulting in a twist per inch (TPI) of 16 for all the yarns. A draft of 4 was given to the elastane filament in all the yarn samples with a tension draft of about 1.1 for the second filament (T400, PET flat, PET textured). These draft levels were selected according to previous studies and are used in industrial production also. The twist level, elastane draft and tension draft for the second filament were kept constant to analyze the influence of the three different filaments (T400, PET flat, PET textured) on the properties of dual-core yarns developed in this study.

Other than studying the influence of different filaments, the effect of two different yarn structures, namely siro versus non-siro, was also investigated on the properties of single and dual-core yarns. For siro yarns, two rovings were used instead of a single one while keeping the yarn count, twist level and draft of elastane and other filaments the same.

2.3. Characterization

Ametek tensile tester equipped with a 100 N load cell was used to study the tensile properties of the developed yarns. The test was carried out according to ASTM D 2256 at a cross-head speed of 25 mm/min at a gauge length of 100 mm. The tenacity of the yarn was determined by dividing the breaking force by the linear density of the yarn. At least three samples were tested for each sample and average values, along with coefficient of variation, were noted for tenacity and elongation at break.

The elastic properties of the single and dual-core siro and non-siro elastane yarns were determined using the same tensile testing machine and subjecting the yarns to repetitive or cycling loading. The gauge length was set at 100 mm and the crosshead speed was set at 25 mm/min. Since the breaking force, as determined from the single yarn tensile test, varied between 8 and 12 N for different yarn samples, therefore, an applied load of 5 N was selected for dynamic or cyclic loading for all the samples for comparison purposes. The selected force falls within the elastic limit of all samples. The cyclic loading was applied for five consecutive cycles. The plastic deformation during cyclic loading was determined using equation (1), as has also been performed by other researchers [5].

$$Plastic\ deformation = \frac{extension\ \%\ after\ 5th\ cycle - Extension\ \%\ after\ afer\ 1st\ cycle}{Extension\ \%\ after\ afer\ 1st\ cycle} X100 \quad 1$$

The quality of the yarns in terms of yarn imperfections (thick, thin places and neps), unevenness, hairiness and Coefficient of mass variation (CVm%) were analyzed using Uster® Tester 3 ASTM D 1425 standard. The moisture-wicking properties of the yarns were determined using an indigenously developed setup where a lea of 120 yards was formed for each yarn sample and immersed in the water bath. The wicking height of the water was noted after specific time intervals of up to 25 min for each sample. For ease of observation, ink was added to the water to determine the wicking height of the water. The wicking height was noted with the help of a measuring ruler. At least three readings were taken for each yarn sample and average wicking height was reported.

3. Results and discussion

3.1. Tensile properties

Fig. 1 shows representative load elongation curves of 10 Ne elastane yarns, both for siro and non-siro ring spun yarns containing either elastane only (single core) or elastane and a second filament (dual-core) either T400, polyester flat (PET flat) or polyester textured (PET textured) filaments. The inferences from the load elongation curves about tenacity and elongation are shown in Fig. 2. It

Table 2
Properties of polyester fibers used in the sheath.

Material	Linear density	Length (mm)	Breaking elongation (%)	Tenacity (Breaking strength) (cN/Tex)	Crimp (%)
Polyester fibers	4.5	38	15	61.69	6.78

Table 3
Details of samples produced in this study.

Sr. No.	Sample type	Sample code	Core 1	Core 2
1	Single core non-siro	SC-E	Elastane	Nil
2	Single core elastane siro	SC-ES	Elastane	Nil
3	Dual-core non-siro	DC-ET400	Elastane	T400
4	Dual-core siro	DC-ET400S	Elastane	T400
5	Dual-core non-siro	DC-EF	Elastane	PET Flat
6	Dual-core siro	DC-EFS	Elastane	PET Flat
7	Dual-core non-siro	DC-ET	Elastane	PET Textured
8	Dual-core siro	DC-ETS	Elastane	PET Textured

can be seen from Fig. 2 that the tenacity of the siro spun yarns is 7.8–14% higher than non-siro yarns.

In the case of siro spun yarns, two rovings are used instead of a single one which gives a doubling effect at the ring frame. Due to this reason, siro yarns have higher uniformity as thick and thin places in one roving are compensated with the other one. The improvement in uniformity is also reflected in Figs. 6 and 7 and will be discussed in respective sections. The uniformity of the yarns has been found to have a direct relationship with the strength of the yarn. The higher the uniformity of the yarns, the higher will be the strength or tenacity of the yarns [22]. The greater evenness of the siro yarns compared with non-siro ring spun yarns is mainly responsible for the greater tenacity of the siro yarns [28].

The tenacity of the dual-core yarn was found to be greater than single-core yarn in the range 4.4–30% with the highest tenacity for dual-core siro yarn containing T400 filaments. Dual-core yarns contain an extra filament that can contribute to load bearing capacity of the dual-core yarns compared with single-core or non-core yarns [9].

The nature of the filament (T400, PET flat, PET textured filaments) also influenced the tenacity of the dual-core yarns. The dual-core yarns containing T400 showed higher tenacity compared with yarns containing PET flat and PET textured filaments. In addition, Fig. 2 also shows that the tenacity of dual-core yarns containing PET flat and PET textured were at similar levels. In literature, significant differences between tenacities of non-core and core spun yarns have been reported. However, the difference in tenacities of single versus dual-core yarns is not as prominent as in the case of non-core versus core spun yarns [17]. In another study, the opposite has been reported where authors found that the tenacity of the dual-core yarns was lower than that of the single-core yarns [21,29]. It is worth noting that the tenacity of dual-core siro spun yarn containing T400 was the maximum among all the yarns produced in this study and up to 25% more than other dual-core yarns. For dual-core yarns, this can be attributed to the difference in cohesion between sheath and core components [21] as no significant difference in the tenacity of core filaments can be observed in Fig. 3(a).

Fig. 2 also shows the elongation percentage of the siro and non-siro single and dual-core yarns containing different filaments. The elongation at break of all the yarns varied within the range of 14.2–19.7%. Compared with non-Siro, siro yarns showed comparatively higher elongation at break. Similar results have been reported in other studies in literature where higher elongation at break is reported for siro spun yarns [30]. The greater tenacity and elongation at break for siro spun yarns can be attributed to greater fiber migration during the yarn formation process [30] and reduced unevenness [31]. Fiber migration refers to the relative movement of fibers concerning their neighboring fibers and determines the position of the fibers in the yarn body.

Dual-core yarns containing PET flat filaments showed relatively lower elongation at break compared with other dual-core yarns which again can be attributed to the difference in cohesion between sheath and core components. In another study, authors reported that siro yarns may have higher as well as lower levels of elongation at break compared with conventional ring-spun yarns depending upon the pretension of the filament [21]. However, the figure shows that the variation in elongation at break is not significantly different in these yarns but it is greater than that reported recently in another study for single and dual-core yarns at similar draft levels [17].

Due to the bicomponent nature of T400, which is composed of two different polyesters having different stretchability giving it crimp, a higher level of stretchability is expected from T400 filament compared with other polyester filaments [9]. Fig. 3 shows no

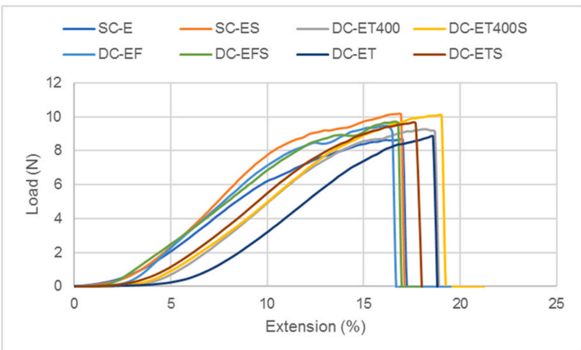

Fig. 1. Representative force-strain curves of single and dual-core elastane yarns.

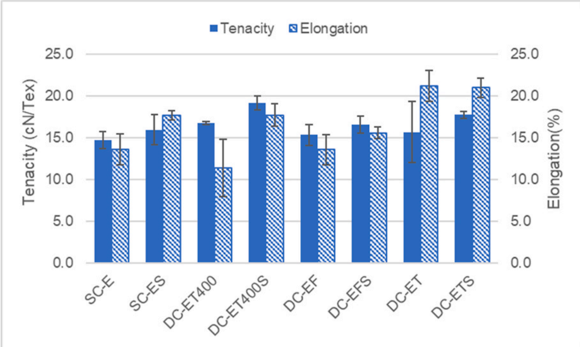

Fig. 2. The tenacity of the yarns determined from single yarn tensile tests.

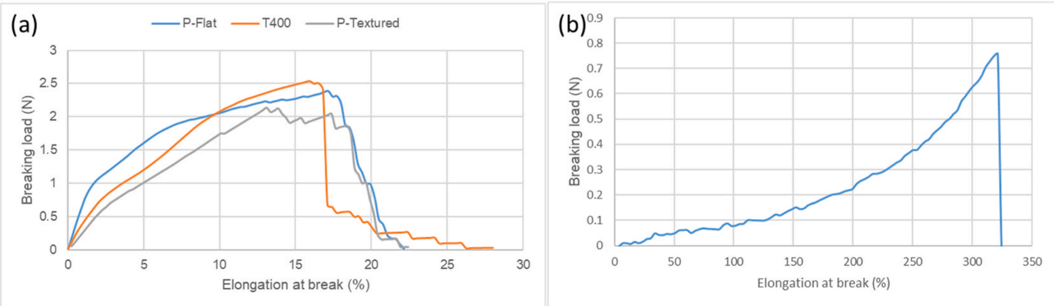

Fig. 3. Load elongation curves of the filaments used in the core: (a) polyester filaments (b) elastane filament.

significant differences in elongation at break for different core filaments. Although Fig. 2 shows differences in the elongation of different dual-core yarns, however, these are not significant. These differences could be due to the core-spun nature of the yarns where cohesion and slippage among constituent fibers and filaments influence the tenacity and elongation of the yarn. In another study, researchers reported that the extent of elongation of the knitted fabric was higher when bare elastane was used in the knitted fabric compared with wrapped elastane [14]. Fig. 3 (b) shows that elastane filament had more than 300% elongation at break that can reflect in the end product if used alone in the core of the yarn.

3.2. *Cyclic loading*

The results of the cyclic loading test of the yarn samples are given in Fig. 4 which shows load versus elongation (%) curves for dual-core siro and non-siro yarns containing T400 filaments only. The repetitive cyclic loading was carried at approximately 50% of the

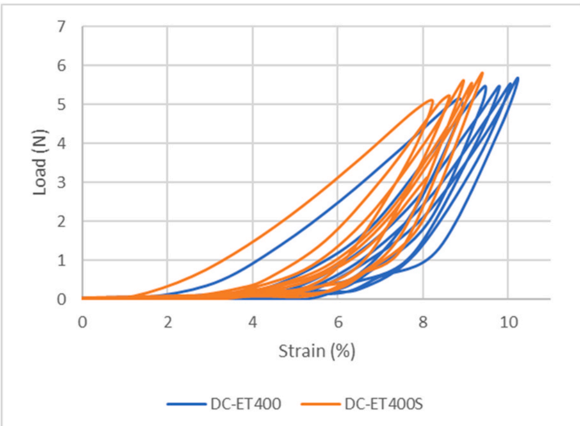

Fig. 4. Representative cyclic loading curves for dual-core-elastane-T400 (DC-ET400) and dual-core-elastane-T400-siro (DC-ET400S) yarns.

breaking load of the yarns. The dimensional stability of stretchable fabrics is important when subjected to repetitive loading and unloading in practical usage. Poor elastic recovery under cyclic loading indicates poor dimensional stability and it may result in undesirable growth giving a loose or baggy effect to the fabric.

Fig. 4 shows that a gradual increase in the elongation of the yarn occurred after each cycle when the yarn was loaded under constant force indicating softening of the yarn after each cycle. It is also evident from Fig. 4 that loading and unloading parts of the curves do not fall on the same path indicating energy dissipation during dynamic loading. The strain energy due to the loading of the yarn is dissipated due to the rearrangement of fibers within the yarn structure and the distribution of the stress within yarn components [9]. This may lead to structural changes in the elastane filament resulting in plastic deformation of the yarns as is evident from Fig. 5. Similar behavior has been reported in the literature for single-core stretch yarns [32].

Fig. 5 shows the plastic deformation of the yarns which is a very important parameter indicating the extent of elastic recovery of the yarns after repetitive loading. It indicates the ability of the yarn to return to its original condition after the removal of the load. The repetitive loading and unloading of the fabric can cause permanent elongation and growth of the fabric and can result in bagging at some parts of the denim fabric [11]. Bagging is a three-dimensional deformation and occurs in the fabric due to complex interaction between tensile and shearing deformation. The plastic deformation was calculated from cyclic loading curves as mentioned in the Material and Method section.

It can be seen from Fig. 5 that the percent plastic deformation is comparable for all the yarns except for the dual-core yarns containing PET flat filaments which showed smaller plastic deformation. It can be seen from Fig. 3 and Table 4 that polyester flat filaments possessed higher initial modulus compared with other filaments. The initial modulus gives the resistance of the filaments to the applied load below the yield point. This could be the reason for the relatively greater recovery of the dual-core yarns containing polyester flat filaments under cyclic loading below the yield point. In another study, it was reported that the filament having a higher initial modulus had lower elongation at break compared with one having a lower initial modulus [33]. Fig. 3 shows no significant difference between stiffness of the T400 and textured polyester filaments and therefore, similar plastic deformation is shown in Fig. 5.

These results provide valuable insight that the stretch and recovery properties of the dual-core elastane yarns can increase the recovery percentage hence dimensional stability of the yarns for denim applications. Thus, the presence of the second filament along with elastane filament and siro spun yarn structure has the potential to tailor the properties of the dual-core yarns.

3.3. Yarn imperfections and evenness

The sum of thick and thin places and neps in the yarn is known as the yarn imperfections index (IPI). The thick (+50%) and thin places (−50%) mean that the cross-section of the yarn at these places is either fifty percent more (+50%) or less (−50%) than the normal cross-section for up to 30 mm of yarn length for a particular count of the yarn. Whereas neps (+200%) mean a thick place of less than 4 mm in length having a cross-section of more than 200% than the normal cross-section of the yarn. The yarn imperfections are given per kilometer of the yarn. The imperfections of the yarn as determined through Uster Tester 3 are shown in Fig. 6 where Fig. 6(a) represents thin places, Fig. 6(b) represents thick places, Fig. 6(c) represents neps and sum of these is given in Fig. 6(d) as imperfections. The figure shows that the imperfections of the siro-spun yarns were significantly lower than that of non-siro yarns. This can be attributed to the doubling effect of the two rovings used to manufacture siro yarns compared with non-siro yarns. As a result, the variations present in one roving are offset by the second roving giving an even yarn with low imperfections. The dual-core yarns showed a lower level of imperfections compared with single-core yarns due to the low number of sheath fibers in the cross-section of the dual-core yarns [12]. The figure also shows that the dual-core yarns showed almost similar levels of imperfections irrespective of the filament with relatively higher levels for the non-siro yarn containing T400 filament.

Fig. 7 the unevenness of the yarns measured as U% using Uster Tester 3. The figure shows that the unevenness (U%) of dual-core yarns is lower than that of single-core yarn indicating a higher level of uniformity for dual-core yarns. Similarly, siro-spun yarns exhibited higher uniformity (lower U%) compared with simple ring-spun (non-siro) yarns. The effect of a higher level of uniformity in the case of the dual-core yarn compared with single-core yarn and siro yarns compared with non-siro yarn is also reflected in the tenacity of the yarns shown in Fig. 2. A similar result has been reported in literature where authors found that the evenness of the dual-

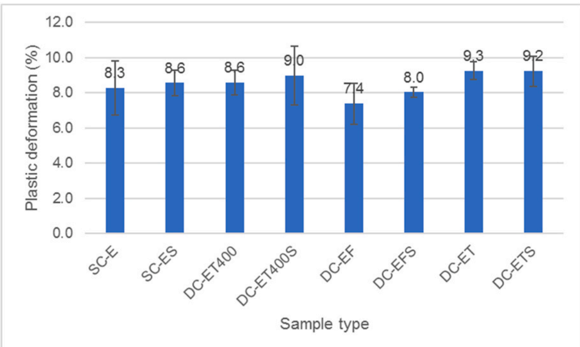

Fig. 5. Plastic deformation of different yarns determined from yarn cyclic loading test.

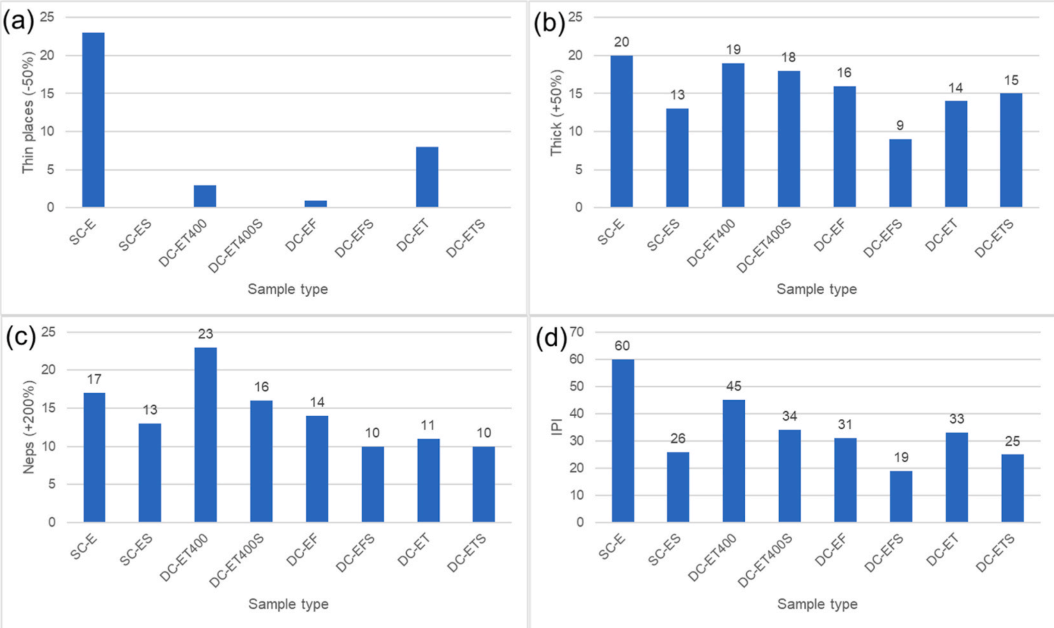

Fig. 6. Yarn imperfections (IPI) of different dual-core yarns developed in this study: (a) thin places, (b) thick places, (c) neps and (d) yarn imperfections (IPI).

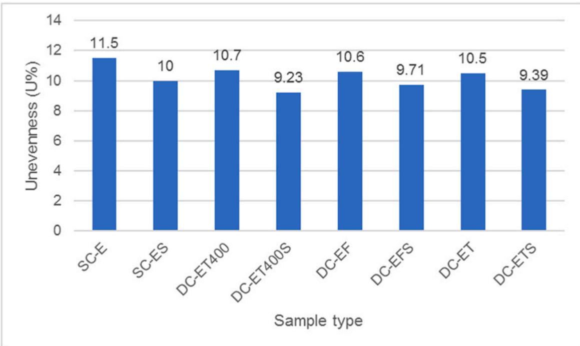

Fig. 7. An unevenness of different yarn samples determined from Uster testing.

Table 4
Tenacity and elongation at break (%) of different core filaments.

	T400	P-Flat	P-Textured	Elastane
Tenacity (cN/Tex)	30.4 ± 2.1	30.4 ± 1.8	28.1 ± 3.6	9.0 ± 0.3
Elongation at break (%)	16 ± 1.2	18.3 ± 1.3	15.0 ± 2.7	379 ± 81
Initial Modulus (cN/Tex)	529 ± 58	754 ± 67	362 ± 102	

core yarns was higher than that of simple ring-spun yarns without any core [9]. Contrary to these results, another study reported higher U% for dual-core yarns compared with single-core yarns [2].

The unevenness of the yarn expressed as (U%) in Uster testing is given in Fig. 7. In agreement with the results shown in Fig. 6, siro-spun yarns exhibited a lower level of unevenness compared with non-siro yarns indicating a higher level of uniformity for siro-spun yarns. However, all the dual-core yarns demonstrated the same level of U% irrespective of the filament. Single-core yarns showed relatively higher unevenness compared with dual-core yarns which can be attributed to the lower number of sheath fibers in the cross-section of dual-core yarns as the bulk of the yarn comprised uniform filaments instead of staple fibers [12]. Single-core yarn contains a higher number of sheath fibers in the cross-section of the yarn that can give higher variation along the yarn length compared with dual-core yarns.

3.4. Yarn hairiness

Fig. 8 shows the hairiness level of elastane yarns containing different filaments. It is evident from the figure that the siro spun yarns, whether single or dual-core, have a relatively lower level of hairiness compared with non-siro or simple ring spun yarns. The dual-core yarns containing different filaments showed similar levels of hairiness irrespective of the use of different filaments. Siro spun yarns are reported to have a lower level of hairiness compared with conventional ring-spun yarns. Siro yarn structures exhibit a lower level of hairiness compared with conventional ring-spun yarns because of their ability to bind sheath fibers within the yarn body [21]. In addition, the hairiness level of the single-core yarns was almost equivalent to the dual-core yarns. A similar effect has also been reported in literature where authors found similar levels of hairiness and unevenness for different dual-core yarns but different tenacities and elongation at break [34].

3.5. Moisture wicking

Moisture handling properties of yarns and fabrics such as moisture absorption, moisture management and moisture wicking play a vital role in the comfort of the wearer. It has been reported that moisture absorption of 3–5% is sufficient to develop a sense of discomfort due to fabric wetness. Therefore, it is important that moisture such as sweat is transported away from the body either in the vapor phase or in liquid form through pores within the yarn and fabric structures to the other side of the fabric [35,36].

Fig. 9 shows the moisture-wicking properties of single and dual-core siro and non-siro yarns with different core filaments. The figure shows that the dual-core elastane yarn containing T400 filament demonstrated the highest moisture-wicking properties. The figure also shows that the siro yarns had the same or in some cases relatively little bit higher level of moisture wicking compared with non-siro (simple ring spun) yarns. This indicates that the yarns containing T400 filament will add to the comfort properties by providing a superior level of moisture wicking compared with other filaments. It will help transport the sweat quickly to the other side of the fabric away from the body and hence give a feeling of dryness in hot weather. The yarns containing PET flat or PET textured showed similar levels of moisture wicking.

Fig. 9 shows that the siro and non-siro yarns had the same level of moisture wicking. It is also evident the dual-core yarns had greater moisture wicking compared with single-core yarns. The dual-core yarns showed 25–85% higher moisture wicking than single-core yarns.

4. Conclusion

In this study, dual-core elastane yarns were developed containing different polyester filaments. Their mechanical properties and dimensional stability in terms of plastic deformation were investigated. The results demonstrated that the tenacity of the siro yarns was 7.8–14% higher than non-siro yarns. Whereas the tenacity of the dual-core yarns was 4.4–30% higher than single-core yarns with the highest value for the dual-core yarn containing T400 filament. However, the plastic deformation or growth behavior of elastane yarns under dynamic or cyclic loading did not change significantly with the filament and siro vs non-siro yarn structures. The dual-core yarns containing T400, PET flat, or PET textured filaments showed similar plastic deformation under cyclic loafing. The moisture-wicking properties of the yarn containing T400 were higher compared with other filaments. The dual-core yarn containing T400 filament showed 27% higher moisture wicking than the yarns containing PET flat or PET textured filament. It can be suggested that dual-core yarn containing T400 with a siro structure is the best regarding yarn strength and moisture-wicking properties. However, dual-core yarn containing filaments with higher initial modulus is recommended for better stretch and recovery under cyclic loading.

Author contribution statement

Muhammad Irfan: Conceived and designed the experiments; Analyzed and interpreted the data, wrote the paper.
Muhammad Bilal Qasedir: Analyzed and interpreted the data, Contributed reagents, materials, analysis tools or data.

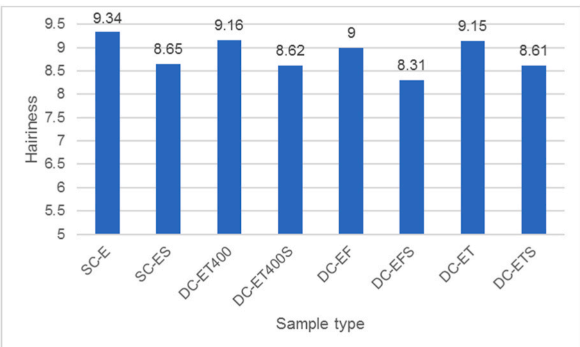

Fig. 8. Hairiness level of different yarn samples developed in this study.

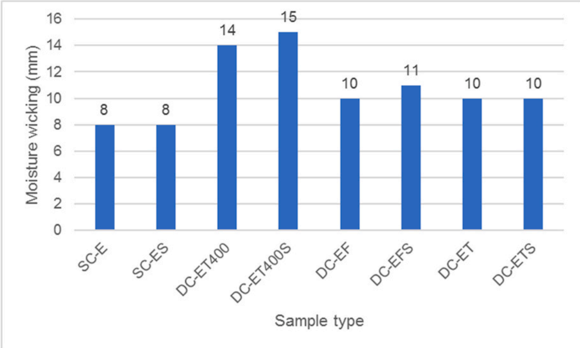

Fig. 9. Moisture-wicking properties of the yarn samples with different yarn structures and filaments.

Ali Afzal: Analyzed and interpreted the data, Wrote the paper.
Khubab Shaker: Performed the experiments; Analyzed and interpreted the data.
Syed Muhammad Salman; Nasir Majeed: Performed the experiments.
Liliana Indrie; Adina Albu: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Data availability statement

Data included in article/supplementary material/referenced in article.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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