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Mechanical Properties of Woven Fabrics Containing Elastane Fibers

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Abstract: Woven fabrics generally have high strength but only limited stretch. This lack of stretch can be overcome by incorporating elastane fibers into the fabric structure. These stretch woven fabrics offer an interesting potential for tight-fitting garments. However, the presence of the elastane fibers may lower the strength of the fabrics. To expand the knowledge on the mechanical behavior of stretch woven fabrics, this study investigated eight commercial fabrics with elastane fiber content between 5 and 51%. Four fabrics were polyester-based and the other four were polyamide-based. The effect of the fabric weight and elastane fiber content on the grab strength, tear strength, and unrecovered stretch was analyzed. It was observed that, at very high elastane fiber content, the load–extension curve was typical to that of an elastane fiber, while the traditional load–extension behavior of woven fabrics with low to average stretch was obtained at lower elastane fiber contents. For the polyester-based fabrics, the grab strength and tear strength generally increased with fabric weight and decreased with elastane fiber content. For the polyamide-based fabrics, a higher elastane fiber content led to a decrease in grab strength, tear strength, and unrecovered stretch. A reduction in tear strength was observed at higher fabric weight.

Keywords: stretch woven fabrics; grab strength; tear strength; unrecovered stretch; elastane fiber; fabric weight

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1. Introduction

Woven fabrics made by the interlacing of warp and weft yarns provide better strength than knitted fabrics [1]. This is due to the interlocking points that impart rigidity to the fabric [2]. However, they are limited in their flexibility and the fit they provide on the body [3]. In addition, they have lower draping abilities compared to knits. Hence, woven fabrics are less desirable in tight-fitted clothing [4]. To take advantage of the strength of woven fabrics while introducing some degree of stretch, elastomeric yarns containing elastane or spandex fibers can be incorporated during the weaving process [5]. Elastane fibers used in both the warp and weft yarns can introduce stretch in all directions of the fabric [6]. This improves comfort as the mobility of the yarns is increased [7]. These fabrics are known as stretch woven fabrics [8]. Stretch woven fabrics have reduced stiffness, which results in better draping ability [3,9].

Stretch woven fabrics containing elastane fibers improve the wear comfort of the garment while maintaining a good degree of strength [5]. Currently, clothing manufacturers opt for stretch woven fabrics in the production of pants, tight-fitted dresses, and tops [3]. However, studies have shown that the strength properties of stretch woven fabrics could be compromised at high elastane fiber content [5,6]. Finding a good compromise between stretch and strength is often a challenge for clothing manufacturers [3,10]. The selection of the right elastane fiber content is complicated by the fact that the yarn type, fabric structure, and nature of the other fibers may also affect the comfort and strength properties of the fabric.

The manner in which the elastane fibers are incorporated into the yarns may also affect the strength, comfort, and hand properties of fabrics. Elastane fibers may be bundled with nonelastomeric yarns to form a traditional multifilament yarn [7]. They can also be introduced as a core-spun yarn in which nonelastomeric fibers are wrapped around a central elastane filament.

Most research on stretch woven fabrics has been focused on cotton/elastane fiber blends. In addition, elastane has often been incorporated in the weft direction, as less strength is required for the weft yarn [11,12]. In addition, more stretch is generally desired in the weft direction. For instance, Choudhary and Bansal investigated the effect of elastane content on the mechanical properties of cotton denim (twill) fabrics [3]. The study compared the 100% denim fabric to two other fabrics with 1 and 1.5% elastane content. This was created by incorporating elastane filaments of two different linear densities in the weft direction. The breaking strength decreased by 18% when the elastane content increased from 1 to 1.5%. The breaking strength was higher in the warp direction compared to the weft direction. The authors attributed it to the presence of the elastane filaments in the weft yarns. Depending on the extension applied, the elastic recovery of the fabrics increased between 1 and 15% with an increase in the elastane content from 1 to 1.5%. It was attributed to the increase in fabric weight with the use of higher linear density elastane filaments. Eryuruk assessed the effect of introducing 2% elastane in cotton woven fabrics [8]. The elastane-containing fabrics had a higher tear strength, by 28 to 52% depending on the direction and fabric finish. This was attributed to the elastane fibers, which made the cotton/elastane fabric more extensible.

Elastane has also been incorporated in fabrics as a core-spun yarn. For instance, Mourad et al. studied the effect of elastane core spun yarns on the tensile, tear, and stretch properties of cotton/ elastane woven fabrics [13]. Five fabrics containing varying contents of elastane core spun yarns in the weft direction were studied. The authors observed that as the elastane content in the fabric increased from 1.23 to 3.68%, the tensile strength decreased by 47%. This was attributed to the fact that elastane fibers have a lower tenacity. The tear strength also decreased by 28% with increasing elastane fiber content because of the lower yarn mobility resulting from the tighter structure at higher elastane content. An increase in the breaking elongation by 127% as the elastane content increased was reported. Regarding the stretch properties, the fabric growth decreased by 58% with increasing elastane content from 1.23 to 3.68% due to the large extensibility of elastane fibers. On the other hand, the elastic recovery increased by 18% since the test was conducted below the elastic limit of the fabrics. Qadir et al. investigated the effect of elastane yarn linear density and draw ratio on the tear and stretch properties of stretch woven fabrics made of cotton in the warp direction and core-spun elastane in the weft direction [14]. The authors reported that the tear strength increased by 61% as the elastane content increased from 3.65 to 5.74% with 40 denier yarns, and by 48% when the elastane content increased from 5.41 to 7.81% with 70 denier yarns. The increase in tear strength with elastane content was attributed to the slippery nature of elastane fibers. The elastic recovery of the fabrics increased by 1.5 to 2% with increasing elastane content. Kumar et al. evaluated the fabric characteristics of denim fabrics containing varying contents of core-spun elastane in the weft direction [15]. The authors reported an increase in the fabric recovery by 20% as the elastane content increased from 0 to 2%. Finally, Ertas et al. evaluated the effect of elastane content on the tensile, tear, and stretch properties of woven denim fabrics, which contained cotton yarns in the warp direction and elastane/polyester dual core-spun yarns with cotton on the outside in the weft direction [11]. A higher breaking force (by 165%) was observed in the weft direction when the number of yarns in the weft direction increased from 12 to 30 yarns/cm. At the same time, the tear strength in the weft direction decreased by 43%.

If many studies have evaluated the effect of elastane on the mechanical properties of polyester/elastane and polyamide/elastane knitted fabrics and a few on cotton/elastane stretch woven fabrics, the knowledge remains much more limited regarding polyester/elastane and polyamide/elastane stretch woven structures. Yet, these fabrics have a large potential for tight-fitting clothing applications. To help fill this knowledge gap, this study evaluated the mechanical and stretch properties of a selection of commercial polyester and polyamide-based woven fabrics containing 5 to 51% of elastane fiber. The effect of the elastane fiber content and fabric weight on the grab strength, tear strength, and unrecovered stretch of the tested fabrics was analyzed.

2. Materials and Methods

2.1. Materials

Eight commercial woven fabrics were selected for this study. Their elastane (ES) fiber content ranged between 5 and 51%. The fabrics were supplied by Tweave LLC, Fall River, MA, USA. Four of the fabrics were blends of polyester (PET) with elastane (PES1 to PES4). The other four fabrics were blends of polyamide (PA) with elastane (PA1 to PA4). Polyester, polyamide, and elastane fibers were present as filaments in the fabrics. Three of the fabrics had elastane fibers only in the weft yarns (PES1, PA1 and PA3). The remainder of the fabrics had elastane fibers in the warp and weft yarns. Figure 1 shows a picture of a stretched strand of weft yarn in PA4. The elastane filament can be distinguished from the polyamide filaments of the yarn.

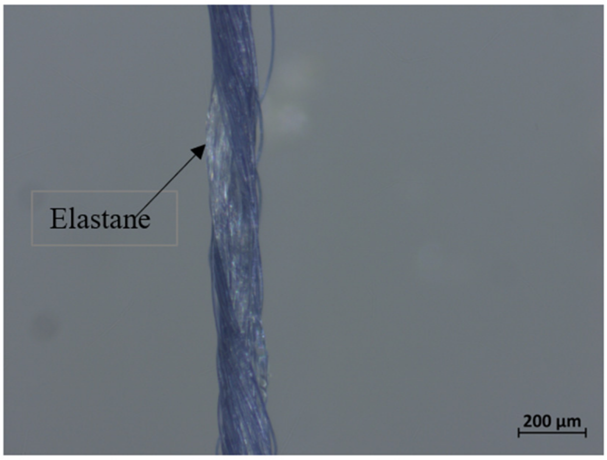

Figure 1. Microscopic image of a stretched strand of the weft yarn in PA4 at 2.5× magnification.

Table 1 lists the characteristics of the eight fabrics. They included various fabric structures: 1/2 basket, 2/1 twill, 2/2 twill, and dooby weave. The weight of the different fabrics varied between 220 and 335 g/m^2. The fabric count ranged between 20 and 50 yarns/cm in the warp and between 34 and 56 yarns/cm in the weft direction. Fabric PA4 had similar fabric count in both directions, while for PES1 and PA1, the fabric count in one direction was more than twice that in the other direction. The thickness of several of the fabrics was in the range of 0.5 to 0.6 mm, while two fabrics (PES3 and PA3) had a thickness of more than 0.8 mm. As the research used commercial fabrics, several parameters varied between the different fabrics, which could constitute a limitation when looking for the controlling parameters of their performance.

It may be noted that, based on the information provided by the manufacturer, PA1 included both regular polyamide filaments, as well as Cordura® textured nylon filaments (Table 1). Texturization is applied to continuous synthetic filament yarns [16]. It may involve imparting crimp, twist, or coiling to the filament and then applying heat setting. The process of filament texturizing has been reported to potentially make the fabric less dense, which can reduce the strength of the fabrics [17,18]. The heat setting increases the heat and dimensional stability of yarns, as well as their tenacity and elasticity [19].

Table 1. Characteristics of the fabrics tested.

Fabric	Fabric Composition *	Fabric Structure	Direction of Elastane Fiber	Fabric Weight (g/m^2)	Fabric Count (yarn/cm) Warp	Weft	Thickness (mm)
PES1	94% PET–6% ES	1/2 basket weave	Weft	264	20	44	0.53
PES2	92% PET–8% ES	1/2 basket weave	Warp and weft	244	30	56	0.58
PES3	91% PET–9% ES	2/2 twill	Warp and weft	220	46	34	0.84
PES4	88% PET–12% ES	2/1 twill	Warp and weft	220	44	34	0.56
PA1	95% PA–5% ES	1/2 basket weave	Weft	278	20	44	0.52
PA2	91% PA–9% ES	2/2 twill	Warp and weft	220	50	34	0.56
PA3	77% PA–23% ES	1/2 basket weave	Weft	335	28	38	0.81
PA4	49% PA–51% ES	Dooby weave	Warp and weft	254	39	39	0.66

* as provided by the fabric manufacturer.

2.2. Methods

All the specimens were conditioned at 20 ± 2 °C and 65 ± 5% relative humidity for at least 24 h prior to testing. The fabric and yarn structures were observed using a Zeiss 508 optical microscope (Oberkochen, Germany). The fabrics were raveled to obtain yarn strands for observation. Images were captured at a 2.5× magnification.

The grab strength measurement was conducted following ASTM D5034 [20]. Specimens with a dimension of 100 × 150 mm were prepared while ensuring that no two specimens contained the same weft and warp yarns. The width of the grips was 25 mm. The test was conducted using a constant-rate-of-extension (CRE)-type tensile testing machine (Model 5565, Instron, Norwood, MA, USA) equipped with a 5 kN load cell. The loading rate was 305 mm/min. The gauge length was set to 75 mm. The maximum grab force recorded was the force required to break at least one yarn in the fabric. In one instance (PA4), no breakage was observed but the fabric did not slip out of the clamps. Ten specimens were tested for each fabric, five in the warp and five in the weft direction. The mean and the standard deviation were calculated for the results in each direction.

The tear strength was measured on an Elmendorf machine (CAT 60-400, Thwing-Albert, West Berlin, NJ, USA) according to ASTM D1242 [21] using a 64 N weight pendulum. Ten specimens with a dimension of 150 × 150 mm were prepared using a cutting die while ensuring that no two specimens contained the same weft and warp yarns. Five specimens were prepared in the weft direction and five in the warp direction.

The fabric stretch and recovery was measured following ASTM D4964, method B [22]. The test was conducted using a CRE-type tensile testing machine (Model 5565, Instron, Norwood, MA, USA) with a 5 kN load cell. Rectangular specimens with a dimension of 350 × 100 mm were prepared while ensuring that no two specimens contained the same weft and warp yarns. Both ends were stitched together to form a loop. Each specimen was mounted on the pin-type clamps of the instrument. The test was conducted at a constant speed of 300 mm/min up to a 30% extension. The test could not be conducted at higher extension levels as the specimen loops began ripping apart. Each specimen was subjected to three cycles of extension and then returned to zero between each cycle. The extension on the return curve of the third cycle when the force equaled zero was used to determine the unrecovered stretch. Ten specimens were measured for each fabric sample, five in the weft direction and five in the warp direction.

The fabric count was measured following CAN/CGSB-4.2, No. 6 [23], using an optical microscope (Zeiss 508, Oberkochen, Germany). Ten different readings were taken in the weft and warp directions. The fabric weight was measured according to CAN/CGSB-4.2, No. 5.1 [24]. Ten circular specimens were cut using a die (50 mm diameter). The measurement was done using a weighing scale (Mettler Toledo PM 2500, Columbus, OH, USA) with a 0.0001 g precision. The fabric thickness was measured following the ASTM D1777-9 standard test method [25] under a pressure of 1 kPa using a presser foot area of 660.5 mm^2 (CS-55-225, Custom Scientific Instruments Inc., Easton, PA, USA).

SPSS 28 (IBM Corp., Armonk, NY, USA) software was used to perform the statistical analysis of the data when relevant. One-way analysis of variance (ANOVA) was conducted to determine the significance of the effect of the fabric weight and elastane content on the grab strength, tear strength, and unrecovered stretch. The confidence level was set to 95% for all the analyses.

3. Results

3.1. Grab Strength

Representative examples of the load–extension tensile curves obtained with the grab test are shown in Figure 2 for each fabric. Seven out of the eight fabrics tested displayed a similar load–extension curve shape. The same behavior was observed in the warp and weft directions. These load–extension curves included an initial crimp interchange region (extending to 2 to 52 mm depending on the fabric) followed by elastic deformation and ultimately breakage. This behavior is typical of what has been reported for fabrics without elastane [26,27]. It has also been observed for elastane-containing woven fabrics with low to average stretch [28,29]. Similar load–extension tensile curves in the warp and weft directions have also been commonly reported for fabrics without elastane, for instance, in this study on plain, twill, and cross twill wool fabrics [30].

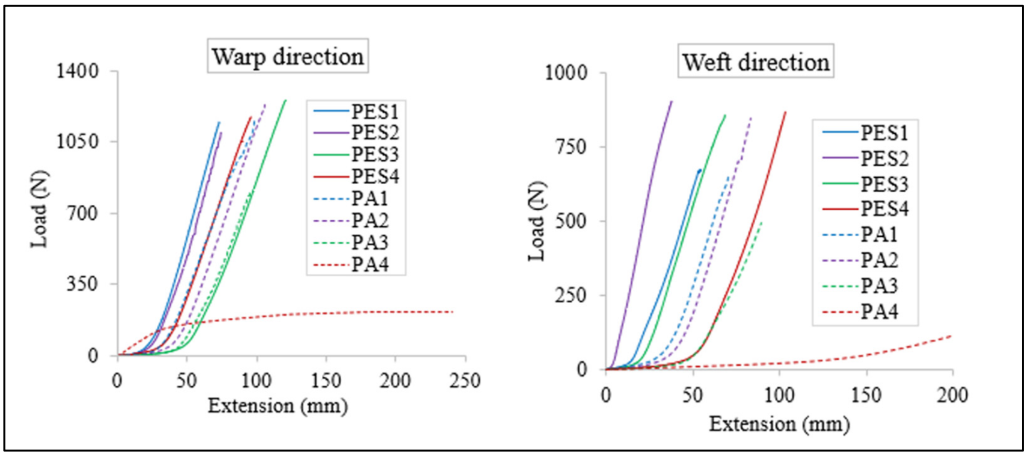

Figure 2. Load–extension curves of the fabrics under study in the warp and weft directions.

Fabric PA4, which contained a much higher elastane content compared to the other seven fabrics (51% vs. 5–17%), showed a highly different behavior (Figure 2). In the weft direction, evidence of crimp interchange could be observed, but it extended up to 150 mm compared to 2 to 52 mm for the other fabrics. In the warp direction, the shape of the load–extension curve was completely different from the weft direction: the curve was initially convex and eventually leveled out. This shape is similar to what is observed when elastane fibers are deformed [31]. Although Klevaityte et al. did not compare the load–extension curves of the twill woven fabrics they studied in the weft and warp directions, these authors reported that the presence of elastane increased the fabric shear and resulted in a higher nonuniformity in the mechanical behavior of the fabrics [32]. In addition, elastane fibers have been reported to decrease the stress transfer in woven fabrics, while increasing their resistance to yarn and fabric breakage [26,29]. Since elastane fibers have a very high extensibility, the elongation at break of fabrics with a high elastane content would be much higher; in our case, it exceeded the capacity of our test frame. For Fabric PA4, the atypical shape of the load–extension curve was thus attributed to its very high elastane content of 51%.

The results in terms of grab strength for the seven fabrics that broke during the test are presented in Figure 3. For the polyester fabrics, the values ranged between 676 and 856 N in the weft direction, and between 1156 and 1251 N in the warp direction. For the polyamide fabrics, the values ranged between 403 and 908 N in the weft direction, and between

797 and 1156 N in the warp direction. For all fabrics, the grab strength was higher in the warp direction compared to the weft direction by 22 to 97% depending on the fabric. This could be attributed to the fact that stronger yarns are generally used in the warp direction to accommodate the higher stress they undergo during weaving [33–35].

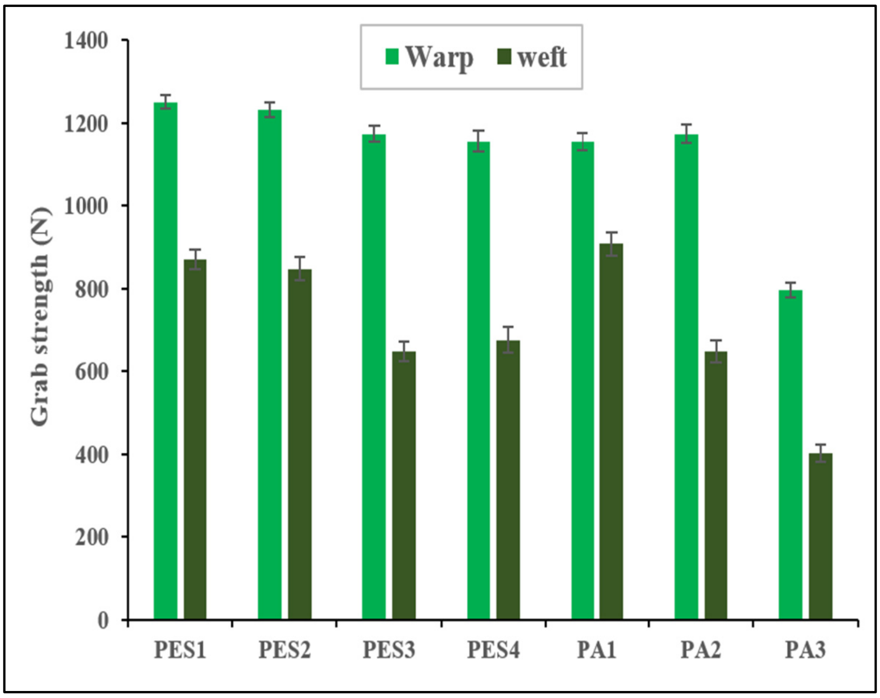

Figure 3. Grab strength of Fabric PES1–PES4 and PA1–PA3 in both directions.

Among the polyester-based fabrics, PES1 and PES2 had similar grab strength values both in the weft and warp directions. Fabric PES3 had a slightly lower strength in the warp direction, while Fabric PES4 had the lowest grab strength in both directions. This might be attributed to the fact that Fabric PES4 had the highest elastane content among all the polyester-based fabrics (Table 1). Regarding the polyamide blends, Fabric PA3 had a much lower grab strength in both directions. In fact, when compared with all the tested fabrics, it exhibited the lowest strength values. It is also the fabric that had the second highest elastane content of all tested fabrics after PA4 (Table 1).

3.2. Tear Strength

Tear tests could not be completed for Fabric PA3 and PA4, as the corresponding specimens slipped out of the clamps of the Elmendorf tester during the test. This is possibly due to their high elastane fiber content as yarns and fabrics containing elastane fibers are generally more slippery [32,36].

The results in terms of tear strength obtained for the six other fabrics are presented in Figure 4. For the polyester-based fabrics, the values obtained ranged between 14 and 30 N in the weft direction, and between 16 and 35 N in the warp direction. The lower tear strength was observed for fabrics with a higher elastane content. Fabric PES1 and PES4 had a lower tear strength in the weft direction compared to the warp direction, while it was the opposite for Fabric PES2 and PES3. For the two polyamide-based fabrics for which the measurement could be performed, the tear strength values were 23 and 30 N in the weft direction, and 23 and 31 N in the warp direction. For these two polyamide fabrics, the differences in tear strength values between both directions were not statistically significant (p = 0.547 for PA1 and p = 0.632 for PA2).

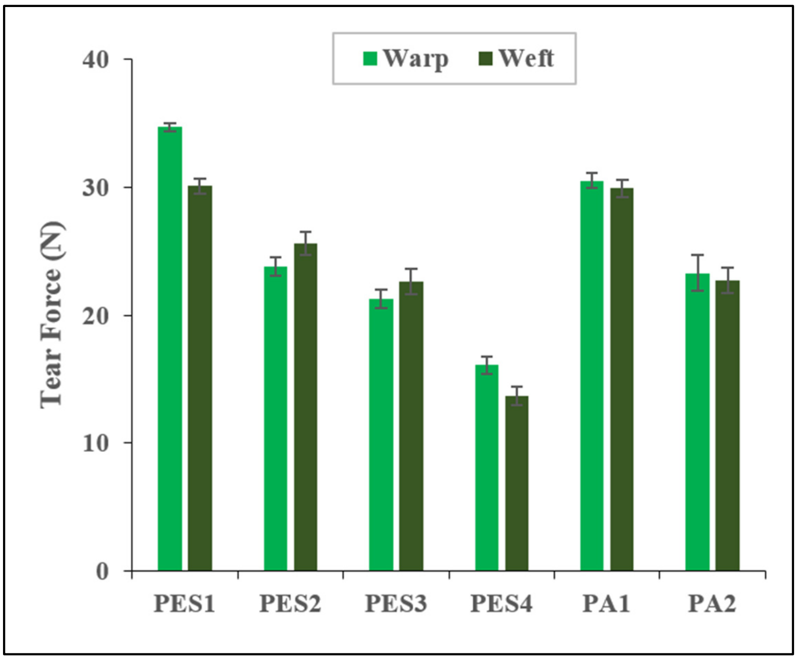

Figure 4. Tear strength of Fabric PES1 to PES4, PA1, and PA2 in both directions.

3.3. Unrecovered Stretch

The results in terms of unrecovered stretch after three cycles of deformation–return at 30% extension are presented in Figure 5. The values obtained ranged between 3 and 11% in the weft direction and between 2 and 10% in the warp direction. For the polyester-based fabrics, Fabric PES1 showed the lowest unrecovered stretch with values of 3% in the weft direction and 2% in the warp direction. Fabric PES3 had the highest unrecovered stretch, with values of 9% in the weft direction and 10% in the warp direction. Fabrics PES2 and PES4 had similar unrecovered stretch values (5% in the weft direction and 4% in the warp direction).

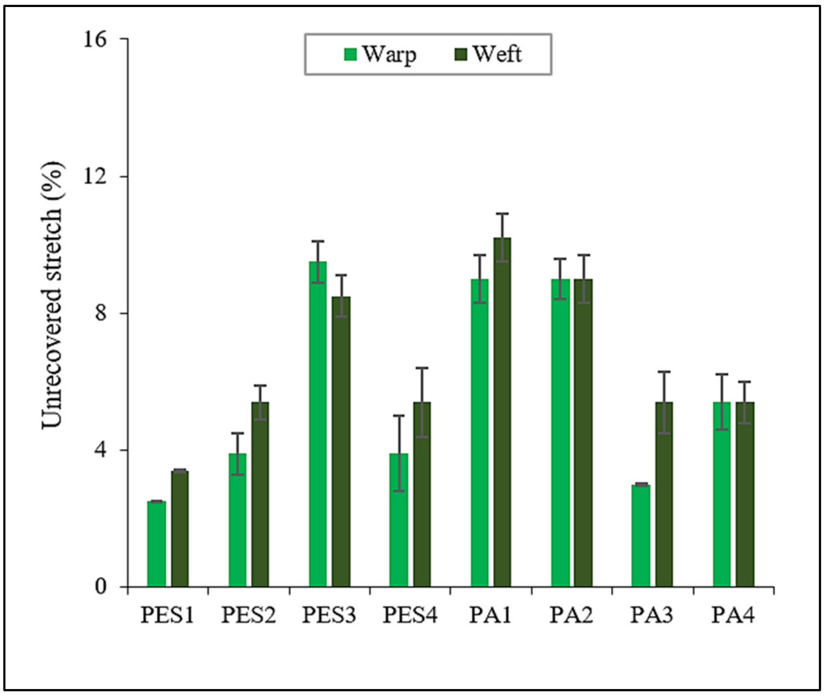

Figure 5. Unrecovered stretch of Fabric PES1 to PES4 and PA1 to PA4 in both directions.

Regarding the polyamide-based fabrics, PA1 had the highest unrecovered stretch, with values of 11% in the weft direction and 10% in the warp direction. PA1 had elastane only in the weft direction. Fabric PA2 had an unrecovered stress of 10% in both directions. On the other hand, a much lower unrecovered stretch value was recorded for Fabric PA3 (5% in the weft direction and 3% in the warp direction). Fabric PA4 had unrecovered stretch values of 5% in both the weft and warp directions.

4. Discussion

4.1. Effect of Fabric Characteristics on the Grab Strength

4.1.1. Effect of Fabric Weight

The variation of the grab strength as a function of the fabric weight is presented in Figure 6. For the polyester-based fabrics in the warp direction, the grab strength increased by 8% when the fabric weight increased from 220 to 264 g/m^2. Two of the data points are almost superimposed. The effect was statistically significant (p = 0.003).

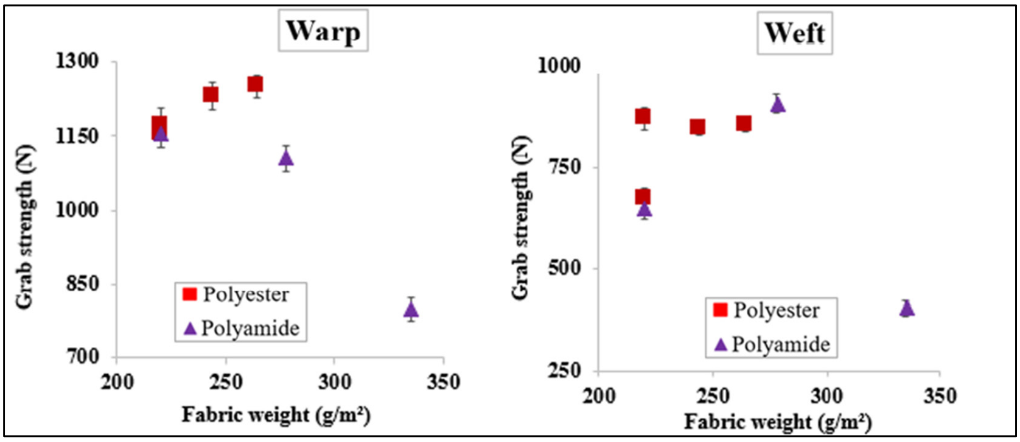

Figure 6. Variation of the fabric grab strength as a function of the fabric weight in both directions.

This positive trend between grab strength and fabric weight in the warp direction agrees with the literature. For example, Mourad et al. reported an increase in grab strength with increasing fabric weight with cotton woven fabrics containing varying elastane-core spun yarn content [13]. The increase in fabric weight was produced by increasing the number of elastane core-spun yarns per unit length of fabric. Erta et al. also evaluated the grab strength of cotton/polyester twill fabrics with elastane core spun yarns [11]. In that case, the fabric weight increase was achieved by increasing the weft fabric count. Similar results were obtained by Choudhary and Bansal after investigating the mechanical properties of stretch denim (twill) fabrics. It is important to note that the same trend has also been reported for woven fabrics without elastane [3]. Ferdons et al. evaluated the grab strength of cotton/polyester woven fabrics, and Jahan assessed cotton fabrics [2,37]. Both studies recorded a positive relationship between grab strength and fabric weight. Grab strength is related to the fabric count: more yarns can take a higher load [34,38]. If the yarn linear density remains constant, fabrics with a higher fabric count have a higher weight [13,39], which leads to the positive relationship between grab strength and fabric weight observed here for the polyester blend fabrics in the warp direction.

In the weft direction, Fabric PES1, PES2, and PES4 followed the same trend as in the warp direction (Figure 6). Fabric PES3 appeared to deviate from this trend. Table 1 shows that it had a higher fabric thickness compared to the other polyester-based fabrics, by about 30% more.

For the polyamide-based fabrics, the opposite trend was observed in the warp direction (Figure 6). No results are included for PA4, for which no break was recorded. For the weft direction, no clear trend can be identified. The deviation of the results for the polyamide-based fabrics from the expected positive relationship between grab strength and fabric weight might be due to the difference in other parameters, for instance, the elastane content, fabric structure, and yarn linear density.

4.1.2. Effect of Elastane Fiber Content

The variation of the grab strength as a function of the elastane content is presented in Figure 7. For the polyester-based fabrics, the grab strength decreased with increasing elastane content in the weft and warp directions. The effect was found to be statistically significant ($p < 0.001$). This observed trend agrees with the literature. Mourad et al. reported that the fabric strength decreased with increasing elastane core yarn content after evaluating cotton/elastane plain weave fabrics [13]. The authors attributed it to the very high breaking elongation and lower tenacity of the elastane fibers. Choudhary and Bansal investigated the effect of the elastane content on the mechanical properties of denim (twill) fabrics [3]. They reported that the breaking strength decreased with increasing elastane content in the weft direction, which was also attributed to the presence of elastane.

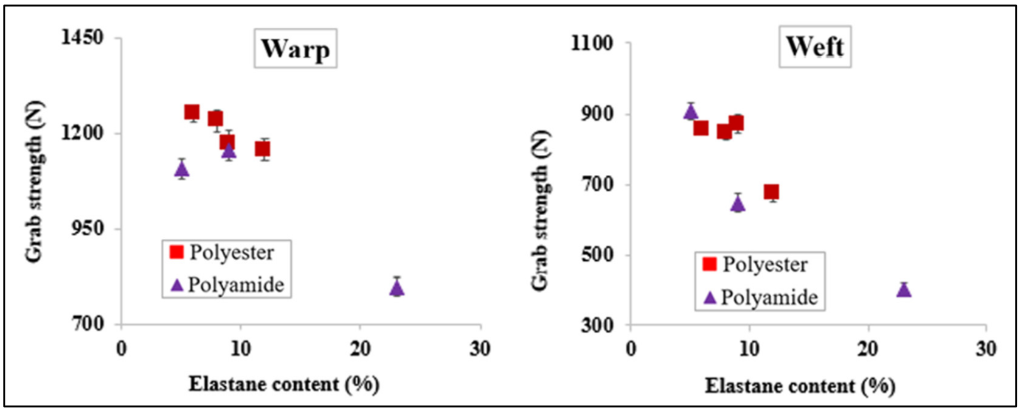

Figure 7. Variation of the fabric grab strength as a function of the elastane content in both directions.

With the exception of Fabric PA1 in the warp direction, the polyamide-based fabrics followed a similar trend as the polyester-based fabrics in terms of relationship between the grab strength and the elastane content. The effect was also found to be statistically significant ($p < 0.001$). Interestingly, the datapoints for the polyester-based and polyamide-based fabrics appear to follow a single curve. No specific reasons have been identified so far for the deviation of Fabric PA1 from this trend. However, other differences such as yarn linear density, crimp, and differences in the weaving parameters could potentially have contributed to this behavior [37,40,41].

4.2. Effect of Fabric Characteristics on the Tear Strength

4.2.1. Effect of Fabric Weight

The variation of the tear strength as a function of the fabric weight is presented in Figure 8. The tear strength of both fabric types increased with increasing fabric weight. The datapoints for both fabric types appear to follow a single curve. For the polyester-based fabrics, the tear strength more than doubled when the fabric weight increased from 220 to 264 g/m^2. The effect was found to be statistically significant in both the weft and warp directions ($p < 0.001$). For the polyamide-based fabrics, the p-value was 0.011 in the weft direction and 0.003 in the warp direction, in both cases within the 0.05 confidence range.

This trend agrees with the results of Qadir et al., who evaluated the effect of fabric weight on the tear strength of cotton woven fabrics containing elastane [14]. The elastane yarns were incorporated in the weft direction. On the other hand, studies involving nonstretch woven fabrics have reported a decrease in tear strength with increased fabric weight. For example, Nassif evaluated the tear strength of micro polyester woven fabrics composed of filament yarns [42]. The fabric weaves were plain, satin, and twill. The authors reported that as the fabric weight increased, the tear strength decreased. The increase in fabric weight was obtained by increasing the fabric count in the weft direction. Similarly, Eltahan investigated the structural parameters affecting the tear strength of cotton woven fabrics [43]. Their results show that the tear strength decreased as the fabric weight increased in both the warp and weft directions.

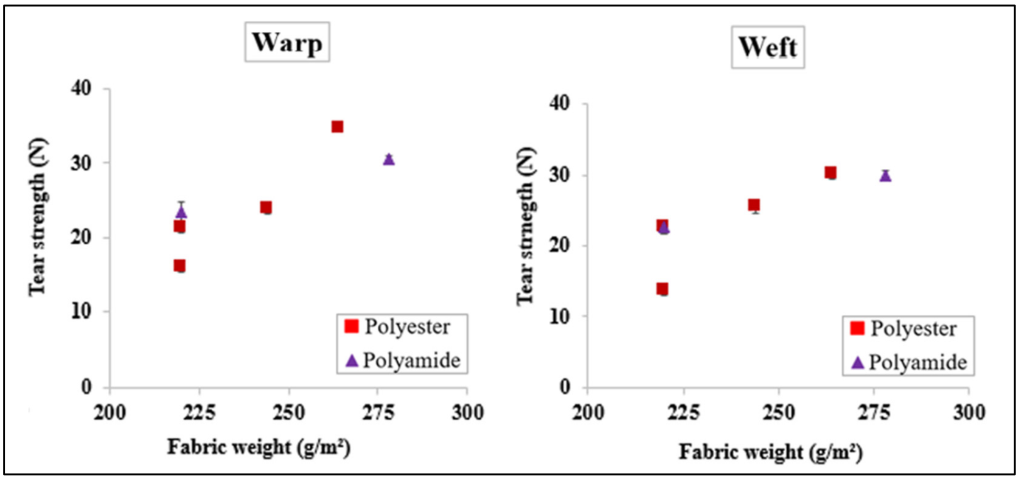

Figure 8. Variation of the fabric tear strength as a function of the fabric weight in both directions.

4.2.2. Effect of Elastane Fiber Content

The variation of the tear strength as a function of the elastane content is presented in Figure 9. It is observed that the tear strength decreased with increasing elastane content for both fabric types. The datapoints for all fabrics appear to follow a single curve. This decrease was found to be statistically significant for the polyester-based fabrics in the weft ($p < 0.001$) and warp ($p < 0.001$) directions, as well as for the polyamide-based fabrics in the weft ($p < 0.001$) and warp ($p < 0.001$) directions. The observed trend agrees with the literature on woven fabrics with varying elastane contents. Mourad et al. evaluated the effect of the elastane content on the tear strength of cotton/elastane woven fabrics [13]. The elastane yarns were incorporated in the weft direction. The authors showed that as the elastane fiber content increased, the tear strength decreased. In another study, Almetwally and Mourad also showed that the tear strength of woven cotton fabrics decreased as the elastane content increased [44]. They attributed it to the lower strength of elastane fibers compared to cotton fibers. The lower strength of elastane fibers compared to polyester and polyamide fibers [45,46] can thus explain the decrease in tear strength of the fabrics as the observed elastane content increased with the stretch woven fabrics of this study.

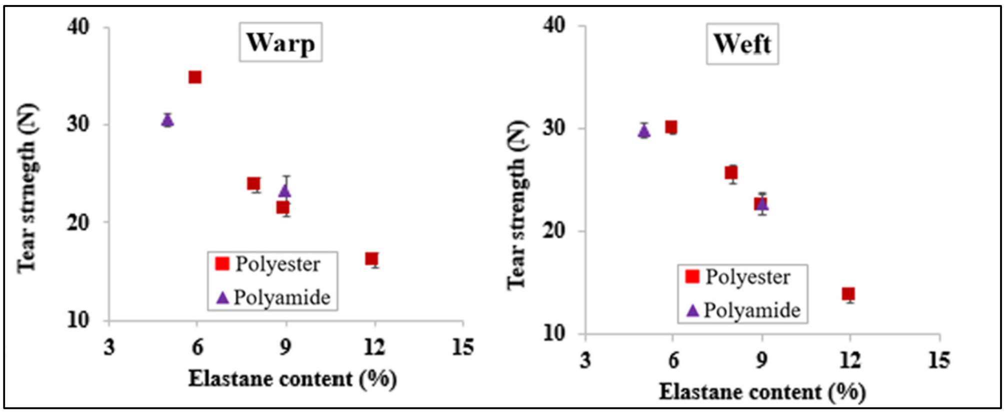

Figure 9. Variation of the fabric tear strength as a function of the elastane content in both directions.

It is important to note that in studies comparing woven fabrics with and without elastane, the opposite behavior was observed. Sacevicienе et al. evaluated the effect of elastane addition on the structural mobility of woven fabrics [7]. As part of their findings, these authors reported that including elastane fibers in the fabric increased yarn mobility, which made the fabrics more tear resistant. This was attributed to the nature of elastane fibers, which are thin and have a low friction coefficient [7,32].

4.3. Effect of Fabric Characteristics on the Unrecovered Stretch

4.3.1. Effect of Fabric Weight

The variation of the unrecovered stretch as a function of the fabric weight is presented in Figure 10. The polyester-based fabrics showed a decrease in the unrecovered stretch by up to three and five times in the weft and warp directions, respectively, when the fabric weight increased from 220 to 264 g/m^2. The effect was found to be statistically significant (p = 000.1 in the weft direction and p = 0.002 in the warp direction). This trend agrees with the literature; for example, the results of Choudhary and Bansal with cotton and elastane woven fabrics [3]. The fabrics contained elastane fibers in the core of the weft yarns. The authors reported that as the fabric weight increased, the unrecovered stretch decreased. This increase in weight was achieved by varying the weft yarn count. Similar results were obtained by Varghese and Thilagavathi [10]. It was attributed to the fact that the fabrics became more compact and stable as their weight increased, which led to a reduction in the unrecovered stretch. In the case of the polyamide-based fabrics, no clear trend was observed.

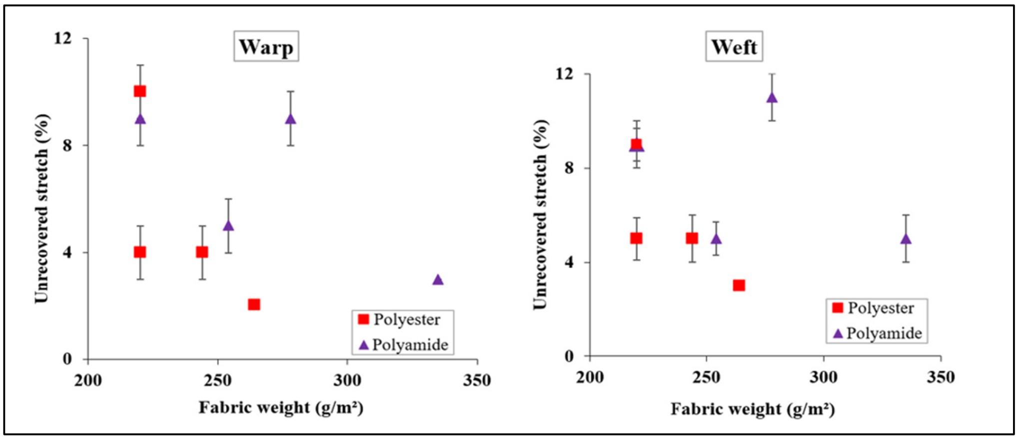

Figure 10. Variation of the fabric unrecovered stretch as a function of the fabric weight in both directions.

4.3.2. Effect of Elastane Fiber Content

The variation of the unrecovered stretch as a function of the elastane content is presented in Figure 11. Except for Fabric PA4, which has a 51% elastane content, the unrecovered stretch of the polyamide-based fabrics showed a decreasing trend with increased elastane fiber content. The effect was found to be statistically significant ($p < 0.001$). This trend agrees with the literature. Choudhary and Bansal evaluated the effect of elastane fiber content on the fabric stretch and recovery of denim fabrics [3]. They showed that as the elastane content increased, the unrecovered stretch decreased. Similarly, Mourad et al. reported that the fabric recovery increased as the elastane content increased with elastane and cotton woven fabrics [13]. This behavior can be attributed to the high extensibility of elastane fibers, which promotes recovery as long as the elastic limit is not exceeded [3,13]. This explains the decrease in unrecovered stretch with increased elastane content observed for Fabric PA1, PA2, and PA3. In the case of Fabric PA4, the difference in behavior observed might be attributed to its very high elastane content (51%), which has shown to lead to a different mechanical behavior than its counterparts with a lower elastane content (Section 3.1).

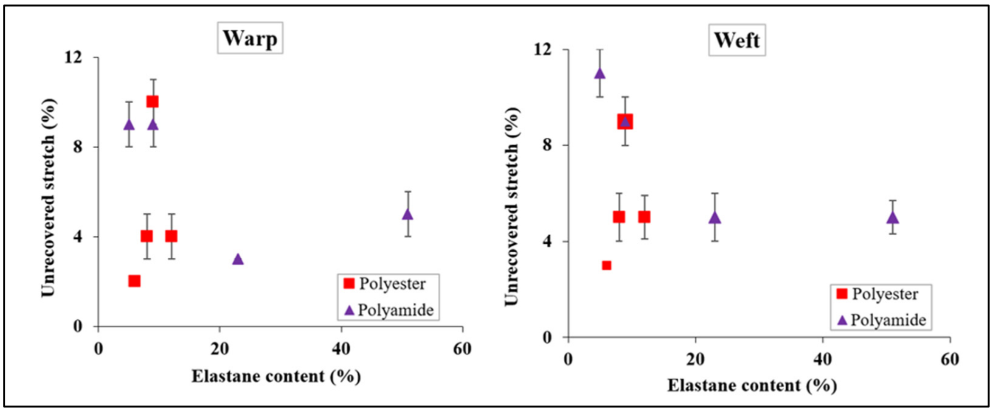

Figure 11. Variation of the fabric unrecovered stretch as a function of the elastane content in both directions.

Regarding the polyester-based fabrics, no clear trend was observed between their unrecovered stretch and elastane content. However, the difference in elastane content between these four fabrics was not very large, and other differences such as yarn linear density, crimp, and differences in weaving parameters could potentially play a larger role on the unrecovered stretch [37,40,41].

4.4. Fabric Selection

The results obtained in terms of strength and stretch for the eight fabrics tested as part of this study were analyzed to determine the fabric that would offer a good compromise between strength and stretch for use in a tight-fitting garment.

Fabric PES1, with 6% elastane, was identified as an interesting option for tight fitting garments among the eight fabrics tested. It had the highest grab strength in the warp direction (1251 N). In the weft direction, it was part of the top achievers with a grab strength of 856 N. In addition, its tear strength was the highest amongst all the tested fabrics, with values of 35 and 30 N in the warp and weft directions, respectively. When considering bra application, these values are well above the minimum requirements of 111 N for grab strength and 6.7 N for tear strength contained in the ASTM D7019 standard specification for underwear fabrics [47]. Minimum grab strength requirements for blouse and dress woven fabrics are also 111 N, while they are 222 N for pants and jackets [48]. Fabric PES1 also had the lowest unrecovered stretch: 2% in the warp direction and 3% in the weft direction. This low value of unrecovered stretch indicates that the fabric is more likely to regain its original shape after deformation and be less prone to sagging.

For tight-fitting clothing applications, the ability of the fabric to stretch is also of large importance. Table 2 shows the value of the force at 30% extension recorded during the stretch and recovery measurement. With 24 N and 18 N reached in the warp and weft direction, respectively, when subjected to a 30% deformation, Fabric PES1 offers a good stretchability compared to other fabrics tested. For bra applications, it also offers a sufficient support considering the value of 12 N for the mean bilateral vertical component of the bra–breast force measured on standing large breasted women wearing sports bras. When running on a treadmill, the value of mean unilateral bra–breast force reached 15 N in low bra support conditions [49].

By comparison, PES2 also had a high grab strength, but its tear strength was about 25% lower and its unrecovered stretch was two times higher compared to PES1. In addition, its stretchiness might be too high for some applications such as bras, for which good support is necessary. Fabric PA1 had values of grab and tear strength close to those of PES1. However, its unrecovered stretch was more than four times that of PES1, which means that the fabric would be more prone to issues of shape retention overtime. Among the two other fabrics than PES1 that exhibited low values of unrecovered stretch, PES4 had a 30% lower tear force and 50% less stretch compared to PES1. In the case of PA3, its grab force was 50%

lower than that of PES1 and its stretchiness was about 50% higher, possibly too high for clothing applications requiring good support.

Table 2. Tensile force at 30% elongation in both directions.

Fabric	Force at 30% Extension (N)	
	Warp	Weft
PES1	24	18
PES2	11	12
PES3	76	81
PES4	54	56
PA1	408	373
PA2	73	79
PA3	12	13
PA4	10	11

When considering fabric selection for tight fitting clothing applications, parameters other than strength and stretch may have to be considered to ensure the durability and comfort of the garment. In terms of durability, it includes the dimensional stability after laundering and resistance to pill formation. For its part, the garment comfort may be affected by the air permeability and water vapor transmission rate of the fabric, its liquid water management properties, and its smoothness.

Another important aspect to consider is the larger importance given to sustainability in textile manufacturing and use. When analyzed within the triple bottom line framework, opportunities for the improvement of woven textile sustainability include the reduction of environmental footprint with lower use of resources and pollution, and increased recyclability [50]. With 6% elastane fiber, PES1 allows limiting the elastane content, which is an issue for recycling, while offering an interesting combination of high strength, good stretchability, and low unrecovered stretch. Progress has also recently been made towards the production of more sustainable highly extensible polymeric fibers, for example, with biobased polytrimethylene terephthalate elastic fibers [51].

5. Conclusions

The mechanical properties of eight commercial woven fabrics with varied elastane contents were measured. Four of these fabrics were polyester-based and the other four were polyamide-based. The elastane fibers were present as filaments and were incorporated in the weft or warp directions depending on the fabrics. The effect of the fabric weight and elastane content on the grab strength, tear strength, and stretch properties was investigated.

The load–extension curves of seven of the eight fabrics tested reflected a behavior that is typical of what has been reported for fabrics with low to average stretch, as well as fabrics without elastane. On the other hand, for the fabric with a very high elastane content (51%), the shape of the load–extension curve observed in the weft direction was similar to what is generally obtained when elastane fibers are deformed. This indicates that at very high elastane content, the fabric's load–extension behavior is controlled by the elastane fibers.

For the polyester-based fabrics, their tear strength increased with increased fabric weight. It was attributed to the fact that heavier fabrics will take more load, leading to an increase in strength. Except for one fabric in the weft direction, this positive trend was also observed for the grab strength results. On the other hand, the fabrics' grab strength and tear strength decreased with increased elastane content. This potentially resulted from the high extensibility of the elastane filaments. Finally, their unrecovered stretch decreased with increased fabric weight, in agreement with the literature. No clear trend was observed between their unrecovered stretch and elastane content.

Regarding the polyamide-based fabrics, a higher elastane content led to a decrease in tear strength. With a few exceptions, a similar negative trend was observed for their grab strength and unrecovered stretch. This was possibly due to the lower strength, low coefficient of friction, and high extensibility of elastane filaments. No clear effect was observed in their unrecovered stretch as a function of the fabric weight. This was attributed to other differences between the polyamide-based fabrics.

Interestingly, the results showed that, despite the differences in fabric structure, nature of the complementary fibers to elastane, fabric count, and other textile characteristics, the datapoints for the different fabrics tested followed single curves when their tear strength was expressed as a function of the fabric weight and elastane content, and when their grab strength was expressed as a function of the elastane content. Based on the obtained results, Fabric PES1 with a 6% elastane content was identified as offering a good combination of strength and stretch, appropriate for tight-fitted garment applications.

The findings of this study provide new insights into the mechanical behavior of stretch woven fabrics composed of polyester and polyamide in blend with elastane fibers. They can also offer some guidance when selecting stretch woven fabrics for tight-fitting garments. This will hopefully allow garment manufacturers to better take advantage of these unique fabrics which combine strength and stretchability. Future research could involve analyzing the effect of the fabric weight and elastane content while keeping the other fabric characteristics constant to elucidate the origin of the exceptions to the trends observed with certain fabrics.

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