(REFEREED RESEARCH)

IN-PLANE SHEAR PROPERTIES OF RIBS FABRIC BY YARN PULL-OUT

RIB KUMAŞIN İPLİK ÇEKME METODUNA GÖRE DÜZLEMSEL KAYMA ÖZELLİKLERİ

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ABSTRACT

The aim of this study was to determine the in-plane shear properties of polyester ribs fabric by the pull-out method and analytical relations were developed to calculate the shearing properties. After the yarn in the fabric was pulled from the top ravel region before the start of the crimp extension stage, it was found that fabric shear strength and rigidity increased when the number of pulled ends increased. When the fabric dimensions increased, fabric shear strength and rigidity also increased. The shear strength and rigidity values in untreated fabric were high compared to that of treated fabric due to the softening treatments. It was observed that fabric sample dimensions and the number of pull-out ends as well as the fabric treatments influenced fabric shear strength and rigidity. In addition, the shear jamming angles were found to be based on the number of pulled ends. Fabric local shearing properties could be identified by pulling the yarn ends in various regions of the fabric. This could be important for the handling of the fabric during formation. The results generated from the study showed that polyester fabric shear could be measured by the yarn pull-out test.

Key Words: Fabric shear, Single and multiple yarn pull-outs, Shear rigidity, Fabric sample sizes, Pull-out fixture.

ÖZET

Bu çalışmanın amacı; polyester rib kumaşların düzlemdeki kayma özelliklerini iplik çekme metoduna göre tanımlamak ve kayma özelliklerinin hesaplanması için analitik bağıntılar geliştirmektir. Kumaşta kıvrımdan dolayı iplik uzaması başlamazdan önce, kumaş kayma dayanımı ve rijitliği, kumaştan çekilen iplik uç sayısı arttıkça artmıştır. Ayrıca, kumaş boyutları arttığında, kumaş kayma dayanımı ve rijitliği artmıştır. Öte yandan, kuru kumaştaki kayma dayanımı ve rijitliği değerleri, yumuşatıcılı kumaşa kıyasla yumşatma maddesi nedeni ile daha yüksektir. Kumaş numune boyutları ve çekilen iplik uç sayıları ile yumuşatıcı muamelesi, kumaş kayma dayanımı ve rijitliğini etkilediği gözlemlenmiştir. Ayrıca, kayma limit açılarının da iplik uç sayısına bağlı olduğu bulunmuştur. Kumaşın bölgesel kayma özellikleri kumaşın çeşitli bölgelerinden iplik çekilmesi suretiyle belirlenebilir. Bu, kumaşın şekillendirilmesi esnasındaki tutumu bakımından önem taşımaktadır. Bu çalışmadan elde edilen sonuçlar, polyester kumaşın kayma özelliklerinin, kumaştan iplik çekme metodu ile belirlenebileceğini göstermiştir.

Anahtar Kelimeler: Kumaş kayması, Tekli ve çoklu iplik çekimi, Kayma rijitliği, Kumaş numune boyutu, İplik çekme testi.

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1. INTRODUCTION

Shearing allows dry fabric to be formed into complex shapes. A simple shear device fixed to a tensile tester was used to measure the simple shear in a fabric. Shear force-angular deformation before the development of local wrinkles and internal yarn-to-yarn friction in the fabric structure were identified (1, 2). It is reported that the largest shear angular deviation was obtained when wrinkles appear (1). Rectangular specimens were better than square specimens due to the latters' tendency to have wrinkling during shearing (3). On the other hand, it was observed that hysteresis occurs when the direction of shear was reversed due to its overcoming the frictional forces that exist in the intersection region between the warp and weft. Frictional forces always oppose applied shearing force (4). A shear tester (KES-F) based on the simple shear test principle was developed by Kawabata (5). It measures the shear properties of fabric under a constant tension. Another method used for measuring fabric shear was by bias-extension where a rectangular fabric sample was cut at 45° in the principal yarn directions and uniaxial tensile load was applied to identify the shear angle (6-9). On the other hand, it was reported that a fixture was developed in the bias-extension method, called the picture-frame (or trellis-frame) to conduct the shear test on a square fabric sample where the shear lock limit was reached (10). There were inconsistencies between the fabric properties measured in simple shear and by bias-extension due to factors including the specimen geometry, thread properties and variation in normal stress during bias-extension (11). Fabric shear behavior was found to depend on applied tension, specimen size and fabric set. It was identified that buckling due to specimen size affected the fabric's shear rigidity (12-14). For a wide range of conventional fabrics, the shear limit was defined by the side-by-side contact of one set of yarns. By using the picture-frame shear test method, a microstructural analysis was carried out in high modulus fiber based fabrics to investigate shear locking on the basis of a geometrical approach and the maximum packing fiber fraction (15). An edge-clamped fabric holding fixture was developed (16). However, transverse tension applied to the fabric through a spring-mounted sliding edge clamp prevented the measurement of the fabric's simple shear. The aim of this study was to determine the in-plane shear properties of polyester ribs fabric by the pull-out method and to interpret the shear behavior of this fabric based on the generated data and develop analytical model.

2. PRINCIPLE OF EXPERIMENT

2.1. Shear force-angle relationship

We can use the simple shear relations to calculate the shear angle. As,

$$w_1 = w_2 = 0.5 \times w \quad (1)$$

and, $\theta_1 = \theta_2 = \theta$, and using the simple shear relations, we get

$$tan\,\theta = [d / 0.5 \times w] \quad (2)$$

Shear angle can be defined as,

$$\theta = \tan^{-1}[d / 0.5 \times w] \text{ (degree)} \quad (3)$$

where, w: Fabric width (m), θ: Shear angle (°), d: Shear displacement (mm). In addition, shear rigidity from the simple shear can be considered (1),

$$F / w = G \times \tan\theta \quad (4)$$

Then, shear rigidity can equal to

$$G = F / w / \tan\theta \ \ (N / m^{\circ}) \quad (5)$$

Specific shear rigidity can be defined as

$$G_{sf} = G / W_f \ \ (N / m^{\circ}\, gm^{-2}) \quad (6)$$

where, F: Pull-out force (N), w: Fabric width (m), F/w: Shear stress, tanθ: Shear strain, G: Shear rigidity, W_f : Fabric areal weight, G_{sf} : Specific shear rigidity. The basic parameters for shear force-angle relationship (θ, w_1, w_2) were shown in Figure 1.

3. MATERIAL AND METHOD

3.1. Woven fabrics

Continuous filaments of polyester air-entangled textured yarn (Advansa, Turkey) were used to produce the woven fabrics. The linear density of this yarn was 33.33 tex and it has 68 filaments in a cross-section. It also has 10/10 cm entanglement. The woven fabrics were designed as 2/2 ribs weave. The warp and filling densities of the fabrics were 38 (ends/cm) and 18 (ends/cm), respectively. The weight of the fabric unit area was 253 (g/m^2). The warp and filling crimp ratios were 28.74 (%) and 4.16 (%), respectively. The fabric thickness was 1.77 (mm). The fabrics were produced by an air-jet weaving machine (Picanol Omni Plus-800, Belgium). Fabrics were treated with non-ionic softening agent (Ceralube SVN liq, Clariant Ltd., Switzerland). The solution, which included 50 g/L softening agent, applied to the fabric by padding method. The pick-up rate was 100%. Treated fabrics were dried under laboratory conditions. Crimp measurement was performed using a Tautex digital instrument (James H. Heal Co., UK) according to ISO 7211-3. The Fabric thickness measurement was performed using an R&B cloth thickness tester (James H. Heal Co., UK) according to ISO 5084. The Fabric weight measurement was performed based on ISO 6348 using an Ohaus Adventurer™ Pro AV812 (Ohaus Corp. USA) digital balance.

3.2. In-plane shear test by pull-out method

Pull-out test fixture was developed to determine fabric shear in the frayed edge of the plain fabric structure (17). For this reason, a pull-out fixture was developed. Figure 1 shows the fixture with the fabric during the shear test by pull-out method in the testing instrument and schematic views of the fabric and yarn pulled-ends for fabric shear by pull-out test before and after test. Fabric from both edges was clamped and special attention was paid to avoid residual tension on the fabric during clamping. In this set-up, fabric shear (fabric displacement) was defined as "displacement that is received under the applied tensile load on single (1 yarn) or multiple yarn ends (2, 3, 4, 5) in the fabric just before the crimp extension, which was defined as yarn length that is received under the applied tensile load on single yarn end in the fabric structure due to interlacement, starts". The maximum fabric shear displacement (fabric displacement) was measured with the assistance of the operator during pull-out testing on the yarn pulled region. Shear force were received by testing instrument. In addition, shear angle was calculated based on shear displacement. Shear rigidity was also calculated based on simple shear principals. Fabric crimp interchange during pull-out test was ignored due to clamped fabric edges. The yarn flattening and slippages in warp and weft directions in the fabric interlacement regions were not considered for simplification purposes. The testing instrument used was the Instron 4411 and the testing speed was 100 mm/min. The fabric widths were 11 cm, 21 cm and 36 cm for the total sample dimension, and 5 cm, 15 cm, 30 cm for the sample dimension in the fixture, respectively. Fabric lengths were arranged 10 cm, 20 cm and 30 cm in all fabric widths. The pull-out direction was in the warp and weft directions of the fabrics. The frayed yarn length in the sample was 15 cm. The width/length ratios of the fabric samples used for this study are considered between 0.5/1 and 1/1. The Instron 4411 pull head drew the individual yarn ends from the frayed edge of the single fabric.

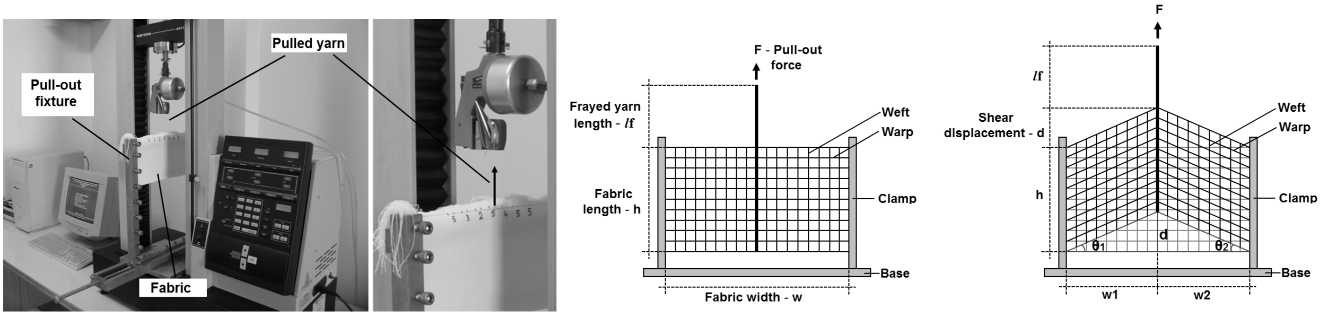

Figure 1. Pull-out fixture with fabric sample on the tensile testing instrument (left), schematic views of the fabric and yarn pulled-ends for fabric shear by pull-out test; Initial fabric position before fabric shear by pull-out test(middle), fabric shear before crimp extension starts (right).

4. RESULTS AND DISCUSSION

4.1. Shear force-angle results

Figure 2 shows the shear force-angle curve for shearing the weft in the fabric during the applications of tensile pulling force to the warp yarns. Fabric shear resulting from the yarn pull-out test was observed. Based on these results, the shear force-angle curve was defined and is shown in Figure 2. When the pulled yarn reaches the point just before where the crimp extension stage starts, this is defined as the maximum shear force-displacement. As seen in Figure 2, there are two regions in the fabric, called A and B, in maximum shear force-displacement. The yarn pulled region is at the centre of the fabric. The A and B regions of the fabric are considered equal. In this case, the shear force-displacement curves seen in regions A and B are equal to each other but, they are in opposite regions in the coordinate system. The tensile base pulled forces and equivalent fabric displacements were recorded. Then, fabric displacement was converted to angular displacement by using equation 3. The shear force-angle curves obtained from the yarn pull-out test appeared to be similar to those in the simple shear and bias-extension shear methods. The initial position of the curves was proportional, but after that it showed a slight non-linear behavior in which there was slight shear angle rotation compared to the increasing level of shear force. The curve was also wavy due to micro slippage between yarn sets at the interlacement region.

Figure 3 shows the shear force-angle curve for shearing the weft and warp in the untreated polyester fabrics during the application of tensile pulling force applied on the warp and weft yarns, respectively. Figure 4 shows the shear force-angle curve for shearing the weft and warp in the treated polyester fabrics during the application of tensile pulling force applied on the warp and weft yarns, respectively. In Figures 3(a) and 4(b), the shear force-angle curves for shearing the weft by 1-5 pulled yarn ends in untreated narrow and wide fabrics, respectively. In Figures 3(c) and 4(d), the shear force-angle curves for shearing the warp by 1-5 pulled yarn ends in untreated narrow and wide fabrics, respectively. It was observed that the shear force-angle curves and the number of pulled ends were proportional. When the number of pulled ends increased, shear force-angle curve also increased. It was also seen that the shear force-angle curves were wavy due to micro-slippage occurred yarn-to-yarn at the interlacement regions.

In Figures 4(a) and 4(b), the shear force-angle curves for shearing the weft by 1-5 pulled yarn ends in treated narrow and wide fabrics, respectively. In Figures 4(c) and 4(d), the shear force-angle curves for shearing the warp by 1-5 pulled yarn ends in untreated narrow and wide fabrics, respectively. It was observed that the shear force-angle curves and the number of pulled ends were slightly disproportional. When the number of pulled ends increased, shear force-angle curve also increased. It was also seen that the shear force-angle curves were wavy due to micro-slippage occurred yarn-to-yarn at the interlacement regions. In addition, fabric sample dimensions and chemical treatments affect the fabric shear obtained from yarn pull-out method.

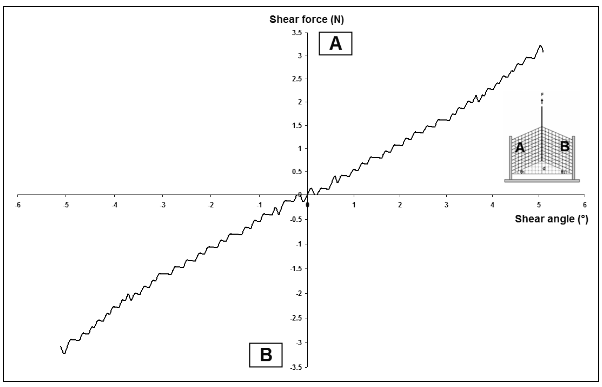

Figure 2. Woven fabric shear force-angle curve in warp direction of fabric part A and B before crimp extension stage. (Fabric; Polyester dry fabric, Pulled ends; 5 yarns, Fabric width and length; 30 x 30 cm.)

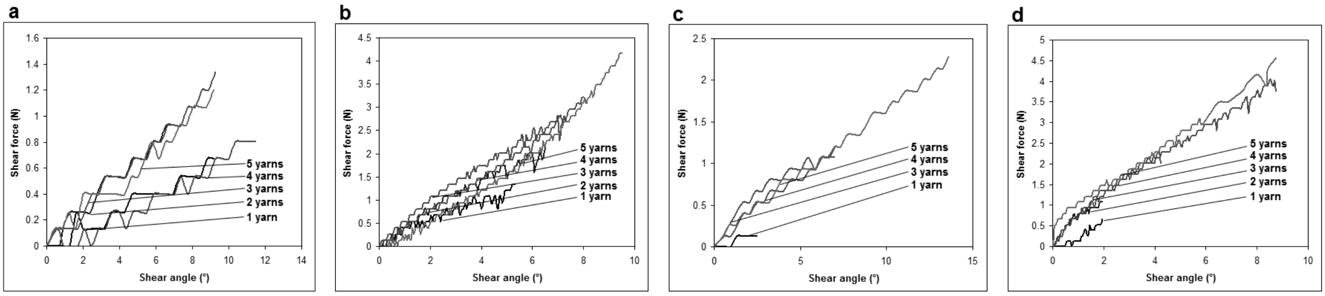

Figure 3. Shear force-angle curves of untreated polyester ribs fabrics. a) Pulled ends:1-5, pulled direction: warp, fabric width: 5 cm, fabric length: 20 cm. b) Pulled ends:1-5, pulled direction: warp, fabric width: 30 cm, fabric length: 20 cm. c) Pulled ends:1-5, pulled direction: weft, fabric width: 5 cm, fabric length: 20 cm. d) Pulled ends:1-5, pulled direction: weft, fabric width: 30 cm, fabric length: 20 cm.

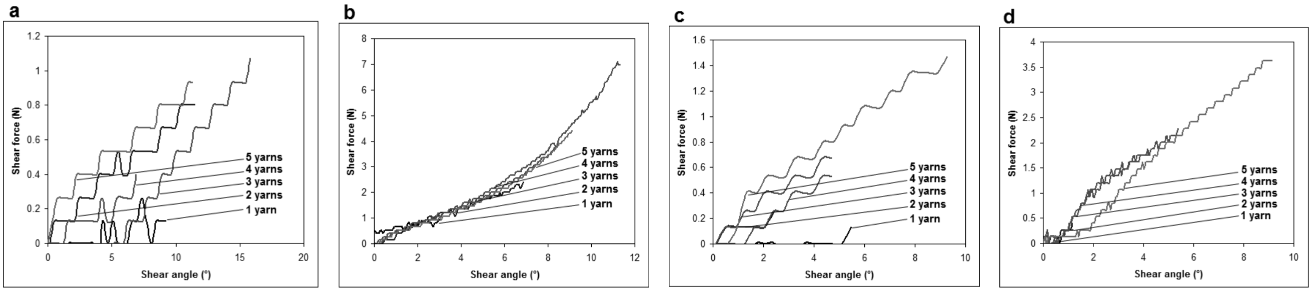

Figure 4. Shear force-angle curves of softening agent treated polyester ribs fabrics. a) Pulled ends:1-5, pulled direction: warp, fabric width: 5 cm, fabric length: 20 cm. b) Pulled ends:1-5, pulled direction: warp, fabric width: 30 cm, fabric length: 20 cm. c) Pulled ends:1-5, pulled direction: weft, fabric width: 5 cm, fabric length: 20 cm. d) Pulled ends:1-5, pulled direction: weft, fabric width: 30 cm, fabric length: 20 cm.

4.2. Effects of sample dimensions and the number of pull-out ends

The warp and weft shear force-angle results for various fabric length and widths, and the number of pull-out ends in untreated and treated fabrics are presented in Figures 5 and 6, respectively. Figure 7 also shows relationship between warp and weft shear force-angle and the number of pulled ends for various fabric width/length ratios in untreated and treated fabrics. As seen in Figures 5-6, when the number of pull-out ends in untreated fabric increased, the shear force-angle values increased in each of the fabric length. On the other hand, the weft shear force-angle values were higher than the warp shear force-angle values. It was not found any significant differences between weft and warp shear force-angle values at various fabric sample length. When the number of pull-out ends in treated fabric increased, the shear force-angle values increased in each of the fabric width. In addition, when the fabric width increased, the shear force-angle values increased in each of the pull-out end.

As seen in Figure 7, when the number of pull-out ends in untreated and treated fabric increased, the shear force-angle values generally increased in each fabric width/length ratios. In addition, when the fabric width/length ratios increased, the shear force-angle values slightly increased. On the other hand, the shear force-angle values in untreated fabric were high compared to that of treated fabric due to the effect of softening agent on the fabric structure. Also, it was found that the warp shear force-angle values were higher than the weft shear force-angle values due to directional fabric density.

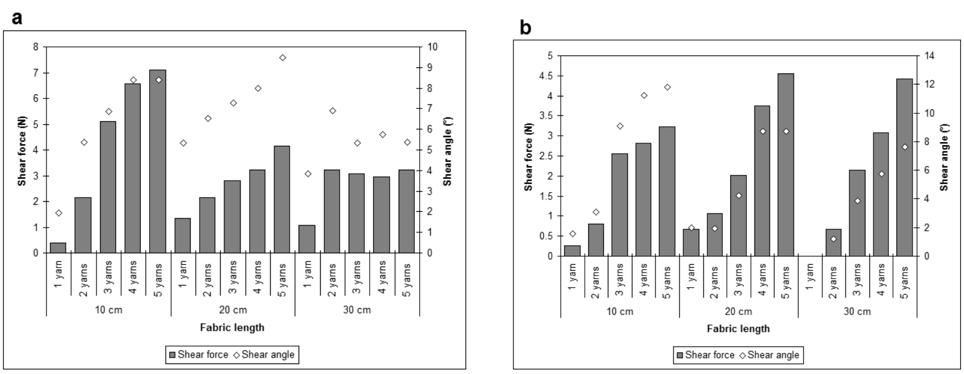

Figure 5. Relationship between shear force-angle and the number of pulled ends for various fabric lengths in dry polyester fabric a) Pulled direction: warp, b) Pulled direction: weft (Fabric width: 30 cm).

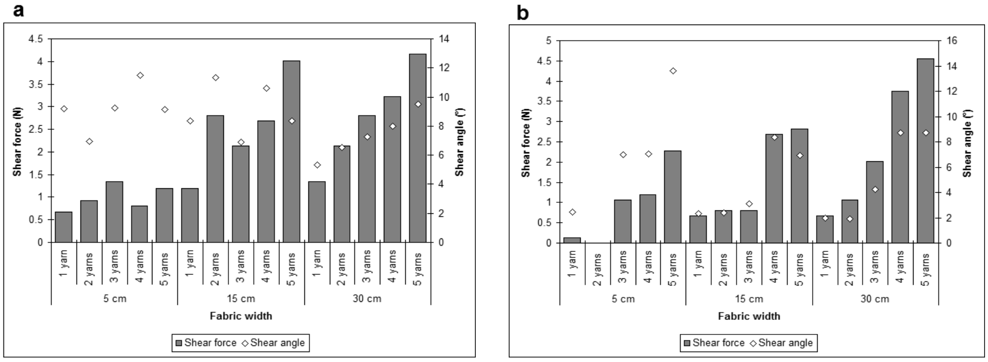

Figure 6. Relationship between shear force-angle and the number of pulled ends for various fabric widths in dry polyester fabric a) Pulled direction: warp, b) Pulled direction: weft (Fabric length: 20 cm).

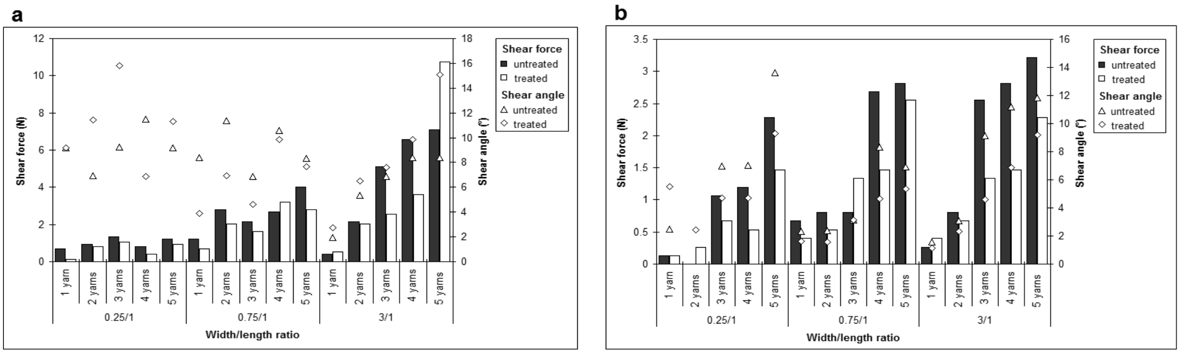

Figure 7. Relationship between shear force-angle and the number of pulled ends for various fabric width/length ratios in untreated and softening agent treated polyester fabric a) Pulled direction: warp, b) Pulled direction: weft.

4.3. Effects of Pull-Out End Position

Shear force-angle values for various pull-out end positions in the fabric sample can be calculated by means of following relations. If the various regional shear angles were $\theta_1 \neq \theta_2 \neq \theta_3 \neq \ldots \neq \theta_n$, and applied forces on the pulled yarn distance in the fabric width were $w_1 \neq w_2 \neq w_3 \neq \ldots \neq w_n$, and the generated shear displacements were $d_1 \neq d_2 \neq d_3 \neq \ldots \neq d_n$, then the following relations can be proposed to calculate the regional shear force-angle values:

$$\tan\theta_n = [d_n / w_n] \quad (7)$$

$$\theta_n = \tan^{-1}[d_n / w_n] \quad (8)$$

Figure 8 shows the schematic views of the tensile pull-out yarn end positions from different fabric regions. The shear force-angle curve for each region can be defined based on the data generated from the tensile testing instruments. From the data, regional shear rigidity can also be calculated. The regional shear force-angle and rigidity values in the woven fabric can be especially important, if the fabric is transformed into varying complex geometrical shapes where local fiber fraction and porosity in the fabric could be affected. More research efforts will be spent to define the fabric's local shearing properties and these will be published separately.

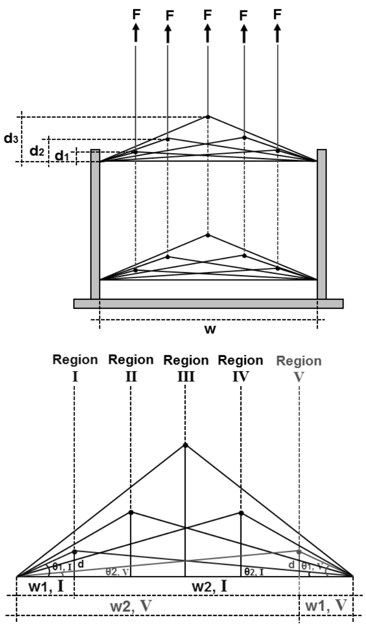

Figure 8. Schematic view of pull-out yarn end positions from different regions of woven fabric during pull-out test to find fabric local shear (left) and top portion of various regional shear displacements and angles (right).

4.4. Shear rigidity results

The shear rigidity results for various fabric length and widths and the number of pull-out ends in untreated polyester fabrics are presented in Figures 9 and 10, respectively. Figure 11 shows relationship between shear rigidity and the number of pulled ends for various fabric width/length ratios in untreated and treated polyester plain fabrics. As seen in Figures 9-10, when the number of pull-out ends in untreated fabrics increased, the shear rigidity values slightly increased in each of the fabric length. Generally, long fabric showed slightly high shear rigidity compared to that of the short fabric. On the other hand, when the number of pull-out ends in untreated fabrics increased, the shear rigidity values increased in each of the fabric width. Generally, wide fabric showed high shear rigidity compared to that of the narrow fabric. As seen in Figures 11, when the number of pull-out ends in untreated and treated fabrics increased, the shear rigidity values increased in each of the fabric width/length ratio. In addition, when the fabric width/length ratios increased, the shear rigidity values decreased in each of the pull-out end.

This indicated that fabric sample dimension and the number of pulled ends greatly influenced the fabric shear rigidity. On the other hand, the shear rigidity values in untreated fabric were high compared to that of treated fabric due to the effect of softening agent on the fabric structure. Specific shear rigidity in untreated and treated fabrics was calculated based on the relationships defined in principle of experiment sub-section of the text. The fabric specific shear rigidity results are presented in Figure 12. As seen in Figure 12, when the number of pull-out end increased, the specific shear rigidity values generally increased. On the other hand, the specific shear rigidity of untreated fabric was higher than that of treated fabric.

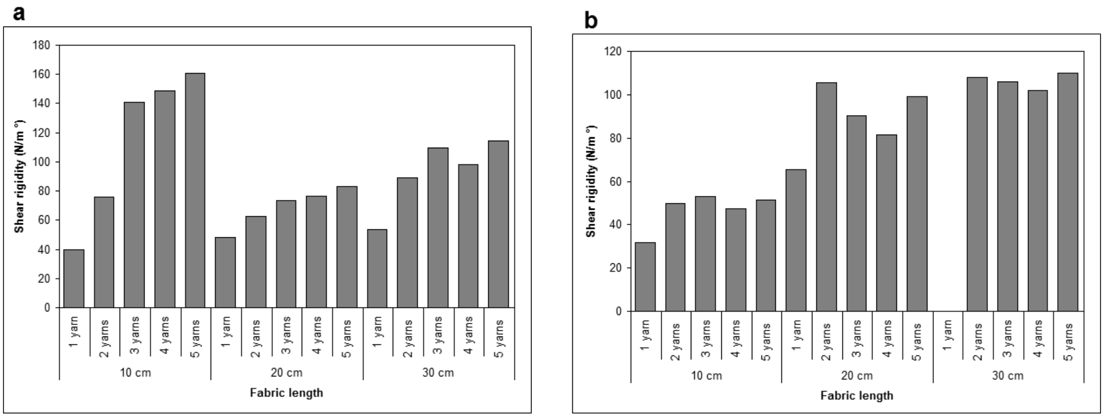

Figure 9. Relationship between shear rigidity and the number of pulled ends for various fabric lengths in untreated polyester ribs woven fabric a) Pulled direction: warp, b) Pulled direction: weft, (Fabric width: 30 cm).

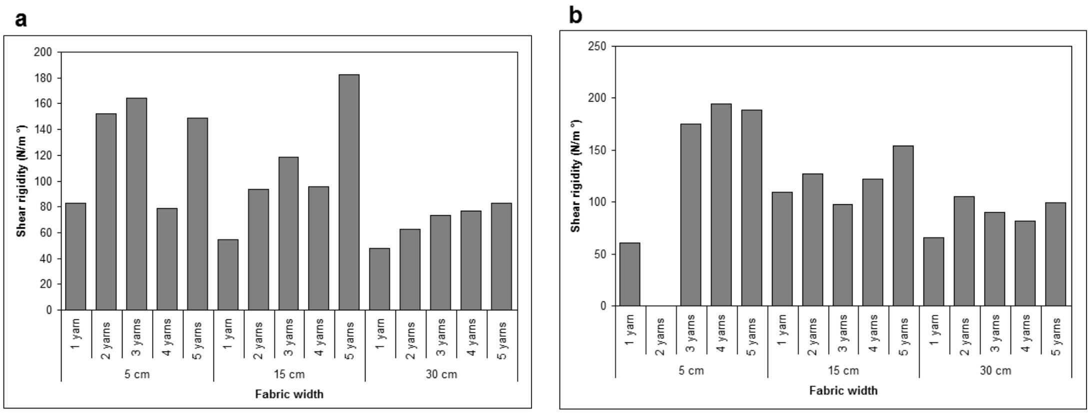

Figure 10. Relationship between shear rigidity and the number of pulled ends for various fabric widths in untreated polyester ribs woven fabric a) Pulled direction: warp, b) Pulled direction: weft, (Fabric length: 20 cm).

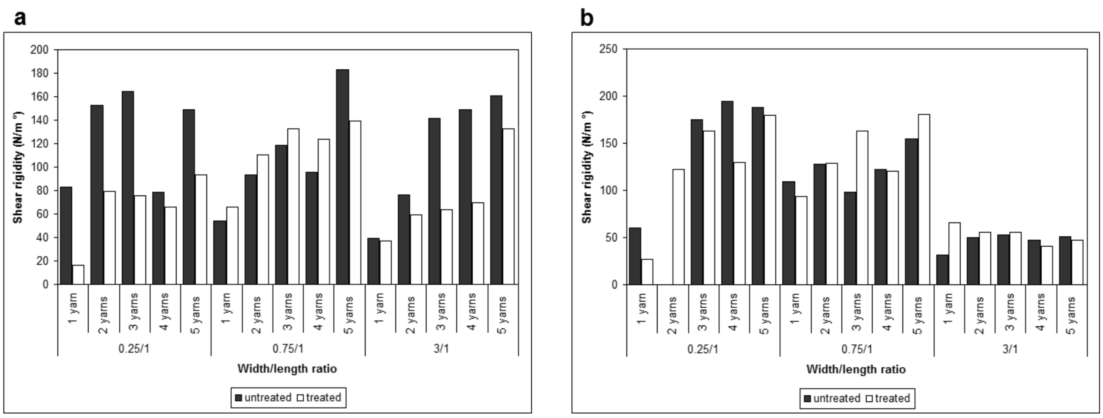

Figure 11. Relationship between shear rigidity and the number of pulled ends for various fabric width/length ratios in untreated and softening agent treated polyester ribs fabric a) Pulled direction: warp, b) Pulled direction: weft.

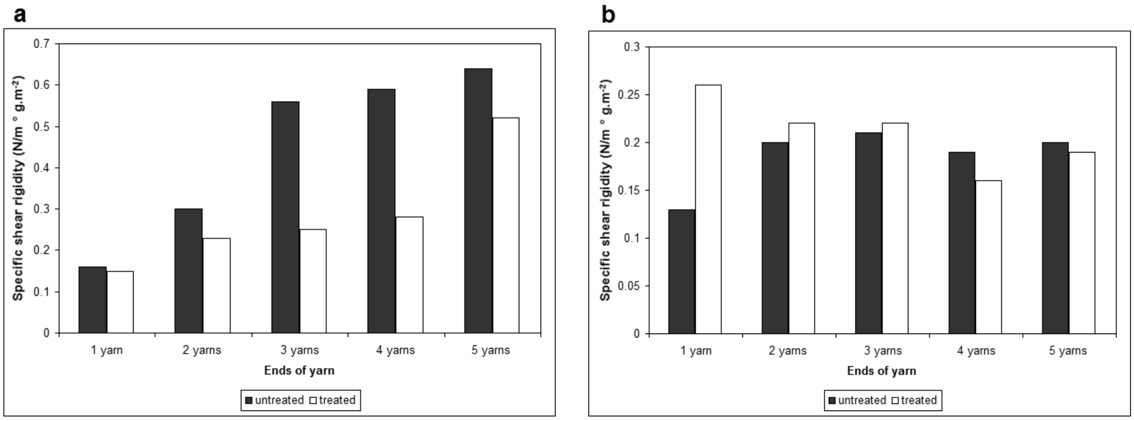

Figure 12. Relationship between specific shear rigidity and the number of pulled ends for various fabric width/length ratios in untreated and softening agent treated polyester ribs fabric a) Pulled direction: warp, b)Pulled direction: weft (Fabric width: 30 cm, fabric length: 10 cm, fabric width/length ratio:3/1).

4.5. Shear jamming results

The warp and weft shear jamming results for various fabric widths and lengths, and the shear angle values in untreated and treated fabrics are presented in Figure 13. As seen in Figure 13, the warp shear jamming angle ranged from 4.75˚ to 11.60˚ for untreated fabric and 4.70˚-17.89˚ for treated fabric in narrow fabric sample for various fabric lengths, whereas the shear jamming angle ranged from 1.94˚ to 9.43˚ for untreated fabric and 2.73˚ to 15.10˚ for treated fabric in wide fabric sample for various fabric lengths. The weft shear jamming angle ranged from 2.42˚ to 13.61˚ for untreated fabric and 2.40˚-9.37˚ for treated fabric in narrow fabric sample for various fabric lengths, whereas the shear jamming angle ranged from 1.19˚ to 11.83˚ for untreated fabric and 0.78˚ to 9.19˚ for treated fabric in wide fabric sample for various fabric lengths. The difference between warp shear jamming angles was around 6.85˚ for untreated fabric and 13.19˚ for treated fabric in narrow fabric sample for various fabric lengths, whereas the difference between shear jamming angles was around 7.49˚ for untreated fabric and 12.37˚ for treated fabric in wide fabric sample for various fabric lengths. The difference between weft shear jamming angles was around 11.19˚ for untreated fabric and 6.97˚ for treated fabric in narrow fabric sample for various fabric lengths, whereas the difference between shear jamming angles was around 10.64˚ for untreated fabric and 8.41˚ for treated fabric in wide fabric sample for various fabric lengths. On the other hand, the maximum warp and weft shear angle value for untreated and treated fabrics in narrow fabric for various fabric lengths was high compared to that in wide fabrics.

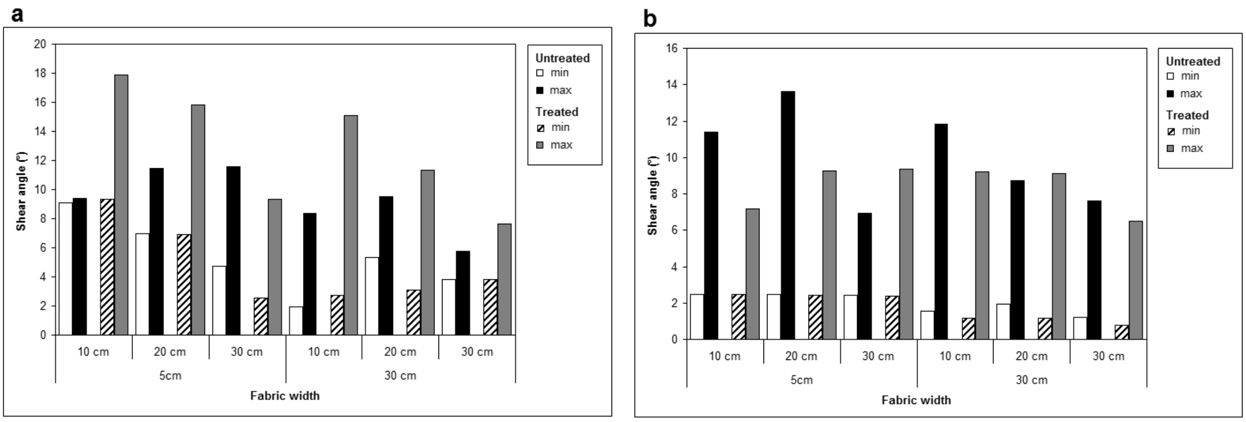

Figure 13. Shear angle jamming for various fabric widths and lengths in untreated and softening agent treated polyester ribs fabrics a) Pulled direction: warp, b) Pulled direction: weft.

5. CONCLUSIONS

Polyester ribs fabrics were tested to define fabric shear by the pull-out method and analytical relations were developed to calculate the fabric shear strength and shear rigidity. Shear strength increased when the fabric width and length, and the number of pulled ends increased. It was found that the weft shear force-angle values were higher than the warp shear force-angle values. On the other hand, when the number of pull-out ends and fabric width, and length increased, the shear rigidity values generally increased. Also, the shear rigidity values in untreated fabric were high compared to that of treated fabric due to the effect of softening agent on the fabric structure. Hence, it was realized that fabric sample dimensions and fabric treatments as well as the number of pull-out ends influenced fabric shear strength and rigidity. Shear jamming angles were found to be based on the number of pulled ends. The maximum and minimum shear angles in untreated and treated fabrics were generated by 5 and 1 ends, respectively. On the other hand, fabric local shearing properties could be identified by pulling the yarn ends in various regions of the fabric which was especially important for fabric handling during formation. The results generated from this study showed that fabric shear could be measured by the yarn pull-out test.

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