Research article

Study on mechanical property of woven fabrics made from 50/50 cotton-tencel blended siro yarn

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ARTICLE INFO

Keywords:
Cotton-tencel
Siro yarn
Twist multiplier
Tensile strength
Plain
Twill
Satin

ABSTRACT

The main objective of this study is to examine the tensile properties of a sustainable woven fabric made of cotton-tencel siro-spun yarn, which is widely used in the apparel industry. Tencel fibers incorporate several excellent sustainability features into their manufacturing process, such as recycling water and chemicals to reduce waste and extracting the trees to sustainably harvested forests. Similarly, cotton is durable, recyclable, and biodegradable, making it an excellent choice as an eco-friendly fabric throughout its product life. The rotational multiplier is a factor that determines how many times the yarn is spun during the spinning process. This refers to yarn strength used in weaving or knitting, as well as the appearance of the finished fabric. All fabrics were made in plain, twill, and satin weaves with warp densities of 100, 95, and 90 ends/inch and weft densities of 60, 55, and 50 picks/inch, respectively. To determine the tensile strength of woven fabric made from 50/50 cotton – tencel siro yarn, elongation at maximum force and force at rupture tests were performed in the greige state as well as after desizing, scouring, and bleaching. The twist multiplier and woven structure were revealed to be largely responsible for the strength of woven fabrics in greige as well as after desizing, scouring, and bleaching. A comparison has made to investigate the rupture force and elongation of proposed technique with ring spun yarn fabrics. In reality, this work demonstrated comprehensive information about the woven fabric properties of 50/50 cotton – tencel siro yarn, which could be useful in understanding their mechanical behavior.

1. Introduction

Tencel fiber is becoming more popular in spinning mills because it can be used in a variety of ways in place of cotton. Tencel is marketed as an environmentally friendly fiber because it is manufactured using a recycled solvent. Tencel has a more drapey, moisture-wicking, and lustrous finish than cotton. It is common practice to combine different fibers to create yarn to obtain the benefits of parent fibers. Numerous articles have been published on the blending of various fibers, and yarn characteristics have been studied experimentally [1, 2, 3, 4, 5, 6, 7]. Barella and Manich [8] and Canoglu et al. [9] investigated the hairiness of blended yarn. Nowadays, viscose, modal, and tencel fibers are melded with cotton to create fabrics with enhanced comfort, stretch, and shininess. Musa Kilic [10] examined the characteristics of 50:50 cotton–tencel blends on a variety of spinning systems. Kilic and Sular [11] investigated the abrasion characteristics of cotton and tencel yarns using a variety of spinning systems. Previously, all spinning processes were optimized for yarn quality and mechanical properties, as well as yield per spinning unit. The agglomeration and arrangement of fibers within the yarn surface are constrained by manufacturing processes. The siro, solo, and compact spinning processes all suggest significant modifications to the conventional ring spinning mechanism to change its spinning triangle's geometry. Over the last two decades, numerous studies upon the characteristics of siro spun yarn and their benefits over conventional yarns were conducted. These studies established that yarns that are manufactured in siro spinning process outperform conventional yarns in a variety of ways [12, 13, 14, 15, 16, 17]. The effects of fibre texture and strand distance on the characteristics of siro spun yarn was investigated by Dhawan et al. [14]. Researchers discovered that the optimal strand spacing for viscose siro spun yarns is 4 mm, which results in improved migration patterns and thus increased strength. Natarajan and Subramaniam investigated the effect of strand spacing on the immigrant pattern of cotton-siro spun yarns [16]. It was discovered that increasing strand spacing results in fiber immigration in siro spun yarns as a result of...
the increased friction. There have been few structural parameter studies of solo-spun yarns. The majority of researchers compared the hairiness of solo- and ring-spun yarns, while others examined the friction resistance of solo-spun yarns in terms of spin magnitude [18, 19, 20]. Researchers discovered that solo-spun yarns have a more uniform distribution of spin magnitude, resulting in a 15% increase in breaking strength over traditional ring-spun yarns, and they examined the strength of solo-spun yarns in comparison to counterpart yarns [21]. Although the first compact spinning machine launched trial production in 1995, research on compact yarn has been ongoing since 1993. Numerous researchers have conducted in-depth studies on compact-spun yarns. They concluded almost unanimously that compact yarns have a better structure, which results in less hairiness and improved mechanical properties, and researchers evaluated by comparing the structure of compact and conventional ring-spun yarns [22,23]. Researchers discovered that compact-spun yarns have a faster rate of fiber immigrants and a larger magnitude of immigrants [24] and their research focused on the inner structure of compact-spun yarns. Researchers discovered that these yarns have a lower average fiber strength than traditional ring-spun yarns; however, a greater RMS variance and average immigrant strength [25]. Researchers discovered that eliminating the spinning triangle in compact spinning systems reduces the immigrant characteristics of compact-spun yarns by approximately 10–25 percent in comparison with the conventional ring-spun yarns [26]. According to the researchers, mechanical compact yarns have lower immigrant parameters than ring-spun and pneumatic compact yarns. Sunay Omeroglu and Sukriye Ulku examined the tensile strength, pilling, and abrasion properties of woven fabrics made from traditional and compact ring-spun yarns and discovered that tensile strength, pilling resistance, and abrasion resistance were all higher in fabrics woven from compact yarns than in fabrics woven from ring yarns [27]. By comparing the mechanical parameters of compact spun yarn woven fabric and ring-spun yarn woven fabric, Alsdair A. Almetwally and Mona M. Salem discovered that there is little difference in tearing strength and abrasion resistance between the two types of materials. On the other hand, fabrics woven from compact yarns excelled in terms of tensile strength, air permeability, and stiffness. BI Song-mei concentrated on the application, expansion, and economic analysis of siro spun. He went into detail in his paper about the Siro spun concept, technical specifications, processing equipment, product specializations, and processing program [28]. Zhang Changle described siro spinning, comparing and contrasting the structural and output characteristics of siro yarn, single yarn, and plied yarn. He observed that siro yarn has low hairiness, a high abrasion resistance, a rapid manufacturing process, and a high economic gain [29]. Chen Yixing is a researcher that focuses on the properties and structure of siro spun yarn. Using a 2–4 factor approach, the effect of various parameters of a redesigned spinning frame for siro spun yarn on yarn quality was investigated. The characteristics of two-fold yarn, siro spun yarn, and the single yarn was compared, and it was found that some prescribed criteria could aid in improving the performance of cotton siro spun yarn. The amount of thread twisting and the structure of siro spun yarn has been established [30]. Kaynak, Incé, Kirecci Ali Hatice Kubra Mehmet Erdem examined the influence of the twist multiplier on the attributes of knitted fabrics manufactured using siro spun, single and two-ply yarns. They discovered that at finer thread counts, plied yarn textiles exhibit lower spirality ratios than siro spun yarn textiles. According to these findings, there may be a better alternative to plied yarn due to the low manufacturing cost and good quality characteristics of siro spun. The conclusion of the research of Ayse Okur compared the characteristics of woven fabrics made of cotton-Tencel blended loop, compact, and vorTex yarns. Cotton-tencel blend yarns in the following ratios have been produced for this purpose: 67:33, 50:50, and 33:67 [31]. P. Soltani and M.S. Johari examined the yarn migration and hairiness of siro, solo, compact, and traditional ring-spun yarns. This analysis used 100 percent tencel fibers [32]. Revenue growth in today's challenging marketplaces is defined not only by revenue growth but also by cost reduction and quality improvement [33]. Consistency is increasingly critical for survival in diverse markets. This necessitates the incorporation of uniformity into the manufacturing process. Tensile strength, elongation percentage, rupture, texture, and breathability are the most significant fabric qualities that determine its quality. Fabric specifications, production technique, and environmental conditions affect fabric qualities. Fabric attributes are influenced by the fiber composition, fabric structure, working environment, machine setting and status [34, 35, 36, 37]. A fabric's weave structure has a substantial effect on its comfort properties, including breathability, thermal conductance, vapor resistance and overall propensity for humidity management. According to a study [38], 3/1 twill fabric has a poorer heat resistance value than 2/2 twill samples. Another study discovered that transitioning from a plain to a twill or satin structure enhances the permeability of water vapor, water absorbivity and penetrability. As fabrics went from plain to twill and satin, their thermal resistance and stiffness diminished. Satin weaves have greater air permeability, water vapor permeability, and rate of water absorption than plain weaves, which have a higher thermal resistance and rigidity [39]. Another study investigated the comfort features of woven fabric architectures such as weft rib 2/2, basket 3/2, plain, twill 3/1, and weft rib 2/2 [40]. The optimal operating conditions for achieving the desired attributes can be determined using theoretical or experimental approaches. The relationship between these characteristics and fabric attributes can be used by the designer to create fabric for a range of purposes [41]. Fabric strength is dependent on the type of raw materials, yarn structure and properties, spinning method, fabric geometry, yarn crimp during processing, weaving conditions (such as temperature, humidity, and yarn tensions during weaving), and fabric finishing treatments, according to the literature [41]. Fabric thickness is influenced by yarn diameter, yarn waviness, and fabric composition. The fabric thickness, the linear density of the threads and then weave all affect air penetration [42]. Analysis of the fabric's stress-strain curves may also aid in forecasting its behavior. The ring spinning method adds value by producing yarn with innovative structures that can be immediately woven or utilized to generate a variety of fancy effects in fabrics. Generally, single yarns are plied in the traditional manner, which entails two phases. Traditional plying begins with winding two or more single yarns onto the bobbins, then twisting the assembly together utilizing plying/folding and two-for-one procedures. In the siro spinning method, two similar or dissimilar roving strands are fed into the drafting system and kept apart throughout the drafting process until the front roller's nipping, using proper guides. Both strands are condensed, twisted, and coiled by the spindle at the delivery roller nip in the classic process. CSIRO (Commonwealth science and industrial research organization) pioneered siro spinning technology in the mid-1970s [43,44]. Spinning speed, strand twists, and yarn fineness all have an effect on strand convergence at the delivery roller; the ideal convergence angle for two strands in equilibrium is 90°, with resonance occurring at 127°. Strand spacing has a considerable effect on packing density, yarn unevenness, hairiness, elongation, and end breakage during the spinning process [45]. According to Yilmaz and Ibrahim, the siro spinning technique excels in terms of tensile characteristics, but the traditional plying approach garners attention for its reduced yarn hairiness and other yarn properties. The hairiness of the yarn was found to be less than that of singles and plied yarns, and when the structure of siro-spun yarn was examined, it was observed that the fiber packing density is not uniform across the cross-section and is not highest in the center [4]. The highest packing density occurs around 1/3rd of the yarn radius from the yarn axis. Siro yarns are more compact than traditional ring-spun yarns, the average packing density of standard ring yarn is lower than that of siro yarn. In comparison to conventional double yarns, siro yarns have a cross-section extremely comparable to that of single ring-spun yarn [46]. Yang Wang Siro spinning significantly increased the minimum yarn strength, according to Yuzheng Lu1. Additionally, by decreasing unevenness and combining the advantages of compact and Siro spinning, compact-Siro spun yarn dramatically improved yarn strength distribution [47]. Serin Mezarçoğ and R. Turul discovered that siro spun fabric had
superior elasticity and growth qualities to ring-spun cloth [48]. Wang, R., and Xiao, Q. examined the pilling resistance of compact siro spun fabrics due to the wrapping of hairy fibers during the spinning process [49]. Hikmet ehit and Hüseyin Kadolu demonstrated that the siro spinning technology significantly minimizes yarn snarling. Siro yarns have a deeper fiber structure, which allows the fibers to sink more deeply. The fibers provide a stronger torsional force than other yarns due to the additional fibers added to the yarn structure according to this approach [50]. Extensive study has been undertaken on the yarn and fabric qualities of modified viscose, tencel, excel, and modal, as well as their relationship to cotton, in the case of ring-spun yarn. However, no research has been undertaken on the fabric qualities of cotton-tencel mixed siro yarn. Tensile qualities of woven fabrics are critical for apparel and other applications design. The most essential fabric qualities that affect the tensile properties of cloth are strength and elongation. Due to the bulkiness of the fabric structure and strain variation during deformation, this research faces numerous difficulties. Due to the huge number of constituent fibers and yarns in each woven fabric, even modest fabric deformation results in a variety of significant changes in the latter [51]. Primary and secondary bonds expand and are shear-loaded in amorphous sections at the start of loading. When the external force is removed, the material regains a significant portion of its expanded length and exhibits elastic qualities. If the loading continues, the material will deform plastically. As a result of secondary bond dissociation, long chains of molecules undergo reciprocal rearrangement. By altering the reciprocal locations of molecules, the material’s ability to endure increased loading is enhanced. If the loading continues, there will be the last break. Two factors define the tensile qualities of woven fabrics: elongation at maximum force and force at rupture [52]. The properties of woven fabric made from 50/50 cotton tencel blended siro spun were investigated in this study. The main goal is to determine the mechanical property of woven fabrics made from 50/50 cotton-tencel siro yarn at the greige state as well as after the desizing, scouring and bleaching treatment to assess the quality of the finished fabric to determine and recommend suitable properties.

2. Experimental

2.1. Materials

The fabrics are made from cotton/tencel blended yarns in a 50:50 ratio. The warp and weft yarns had a count of 25/1Tex and were spun with three twist multipliers: 3.8, 4.0, and 4.2. The siro spinning method was used to manufacture all of the yarns. The physical parameters of the yarns are listed in Tables 1, 2, and 3 according to the spinning method.

Figures 1 and 2 compares the parameters of the yarns. Unevenness (U%) of the yarns ranges from 10-11 (Figure 1) while hairiness value was found around 5 (Figure 2). Highest value of thin place was seen for the yarn with TM value 4 while thick place and neps content were found almost similar for all. Several chemicals were used for sizing, scouring, and bleaching, all of which were purchased from Huntsman, Singapore and used without any purification. The chemicals Kieralon FR-HB, Lufibrol red, Lufibrol EX, Kieralon wash FALB, and Kieralon jet B.com were used for sizing. Scouring and bleaching chemicals included H2O2 (50 percent), NaOH (360 Be’), Stabilol Zm, Cottonclarin BLN, and Securon C540.

2.2. Sample preparation

All of the fabric samples were woven using a miniature air-jet weaving machine. The characteristics of woven fabric samples are mentioned in Table 4. The fabrics were created using a 1/1 plain, 2/2 twill, and 5 end satin weave structure with three different warp densities: 100 ends/inch, 95 ends/inch, and 90 ends/inch, as well as three different weft densities: 60 picks/inch, 55 picks/inch, and 50 picks/inch. In both the warp and weft directions, yarns with a count of 25/1Tex were used. These specific yarn densities were selected because these are most commonly used for fabric production in the industry.

Table 1. Yarn test result of 25/1 Tex, 3.8TM yarn.

| Sl No | U% | Hairiness (above 3mm/10m) | Thin -30% /km | Thick +50% /km | Neps +200% /km |
|-------|----|--------------------------|--------------|-------------|--------------|
| 1     | 10.25 | 5.00 | 755.0 | 220.0 | 237.5 |
| 2     | 10.65 | 6.00 | 917.5 | 227.5 | 250.0 |
| 3     | 10.67 | 8.00 | 930.0 | 182.5 | 207.5 |
| 4     | 10.05 | 4.00 | 650.0 | 205.0 | 217.5 |
| 5     | 10.06 | 6.00 | 702.5 | 232.5 | 250.0 |
| 6     | 10.45 | 5.00 | 697.5 | 190.0 | 292.5 |
| 7     | 10.86 | 4.00 | 1107.5 | 252.5 | 295.0 |
| 8     | 10.30 | 4.00 | 822.5 | 212.5 | 220.0 |
| 9     | 10.54 | 6.00 | 870.0 | 225.0 | 247.5 |
| 10    | 11.28 | 3.00 | 1392.5 | 287.5 | 352.5 |
| Mean  | 10.51 | 5.10 | 884.5 | 223.5 | 257.0 |
| CV%   | 3.42  | 26.96 | 24.11 | 12.9 | 16.40 |
| Max   | 11.28 | 8.00 | 1392.5 | 287.5 | 352.5 |
| Min   | 10.05 | 3.00 | 650.0 | 182.5 | 207.5 |

Table 2. Yarn test result of 25/1 Tex, 4.0 TM yarn.

| Sl No | U% | Hairiness (above 3mm/10m) | Thin -30% /km | Thick +50% /km | Neps +200% /km |
|-------|----|--------------------------|--------------|-------------|--------------|
| 1     | 11.38 | 6.00 | 1283 | 197.5 | 222.5 |
| 2     | 10.50 | 4.00 | 808 | 227.5 | 290.0 |
| 3     | 10.77 | 5.00 | 1088 | 190.0 | 252.5 |
| 4     | 11.44 | 7.00 | 920 | 200.0 | 220.0 |
| 5     | 10.83 | 4.00 | 890 | 217.5 | 242.5 |
| 6     | 10.90 | 4.00 | 1025 | 265.0 | 287.5 |
| 7     | 10.41 | 5.00 | 800 | 230.0 | 225.0 |
| 8     | 11.28 | 6.00 | 1210 | 232.5 | 305.0 |
| 9     | 11.36 | 5.00 | 1293 | 240.0 | 237.5 |
| 10    | 11.21 | 4.00 | 1215 | 237.5 | 230.0 |
| Mean  | 11.01 | 5.00 | 1053 | 223.8 | 251 |
| CV%   | 3.25  | 20.00 | 17.30 | 9.70 | 11.90 |
| Max   | 11.44 | 7.00 | 1293.0 | 265.0 | 305.0 |
| Min   | 10.41 | 4.00 | 800.0 | 190.0 | 220.0 |

Table 3. Yarn test result of 25/1 Tex, 4.2 TM yarn.

| Sl No | U% | Hairiness (above 3mm/10m) | Thin -30% /km | Thick +50% /km | Neps +200% /km |
|-------|----|--------------------------|--------------|-------------|--------------|
| 1     | 10.59 | 8.00 | 862.5 | 197.5 | 192.5 |
| 2     | 10.28 | 6.00 | 742.5 | 242.5 | 275.0 |
| 3     | 11.01 | 4.00 | 1137 | 270.0 | 245.0 |
| 4     | 11.38 | 4.00 | 1332.5 | 227.5 | 245.0 |
| 5     | 10.29 | 5.00 | 680.0 | 240.0 | 272.5 |
| 6     | 10.62 | 3.00 | 895.0 | 180.0 | 215.0 |
| 7     | 10.80 | 6.00 | 927.5 | 217.5 | 222.5 |
| 8     | 11.03 | 7.00 | 1210 | 275.0 | 282.5 |
| 9     | 10.25 | 5.00 | 787.5 | 162.5 | 210.0 |
| 10    | 10.94 | 5.00 | 1137 | 210.0 | 202.5 |
| Mean  | 11.38 | 6.00 | 1283 | 197.5 | 222.5 |
| CV%   | 3.72  | 26.75 | 21.43 | 15.55 | 13.04 |
| Max   | 11.38 | 8.00 | 1332.5 | 275.0 | 282.5 |
| Min   | 10.25 | 3.00 | 680.0 | 162.5 | 192.5 |
rupture force increased as well. At 3.8 TM, the rupture force was the lowest, and as the TM value rose, the lowest. The twist multiplier (TM) has an impact on the rupture force. At structures was the highest, twill was the second highest, and satin was the highest, twisting than in the weft direction. The rupture force of plain fabric directions. It was discovered that the rupture force is stronger in the warp direction than in the weft direction. The rupture force of plain fabric was determined in both warp and weft directions. It was revealed that the rupture force is stronger in the warp direction than in the weft direction. The rupture force of plain fabric structures was the highest, twill was the second highest, and sati was the lowest. The twist multiplier (TM) has an impact on the rupture force. At 3.8 TM, the rupture force was the lowest, and as the TM value rose, the rupture force increased as well.

The rupture force of the fabric was determined in both warp and weft directions. It was discovered that the rupture force is stronger in the warp direction than in the weft direction. The rupture force of plain fabric structures was the highest, twill was the second highest, and satin was the lowest. The twist multiplier (TM) has an impact on the rupture force. At 3.8 TM, the rupture force was the lowest, and as the TM value rose, the rupture force increased as well.

Figure 2 depicts the force at rupture. The initial rupture force for a 100 × 60 plain fabric with a 3.8 twist multiplier was 360.23 N, and it grew as the twist multiplier value climbed, peaking at 380.1 N for a 4.2 twist multiplier. The force at rupture values for 95 × 50 plain fabric were nearly comparable. The initial rupture force for a 95 × 50 plain fabric with a 3.8 twist multiplier was 338.96 N, increasing as the twist multiplier value increased, peaking at 350.29 N with a 4.2 twist multiplier value. For a 100 × 60 twill fabric, the initial rupture force was 333.38 N for a 3.8 twist multiplier, and it increased as the twist multiplier value increased, reaching 370.18 N for a 4.2 twist multiplier value. The initial rupture force for a 95 × 50 twill fabric with a 3.8 twist multiplier was 311.71 N, and it climbed as the twist multiplier value increased, topping 339.4 N for a 4.2 twist multiplier value. The perhaps the first rupture force for a 90 × 55 twill fabric with a 3.8 twist multiplier was 280.56 N, peaking at 317.44 N with a 4.2 twist multiplier value. The initial rupture force for 100 × 60 satin fabric peaked at 364.4 N, while the 95 × 50 satin fabric peaked at 327.42 N. The rupture force was increased to almost 290 N with 4.2 TM value from the initial 261.96 N rupture force with 3.8TM value for 90 × 55 satin fabric. Force at rupture was discovered to be higher in the warp direction than in the weft direction. This may be because sizing material on the warp yarn causes a rise in elongation, making the greige fabric stronger. In addition, as the twist multiplier in the warp and weft increases, the tensile strength in both directions increases until the multiplier reaches 4.2 (Figures 3 and 4).

The findings are confirmed by related patterns found in yarn tensile strength. The yarn packing coefficient increases as the twist multiplier increases due to increased inter-fiber friction. However, above an optimum twist stage, which appears to be 4.2 in this case, fiber rupture decreases tensile strength due to these fibers' negligible contribution.

In both the warp and weft directions, it was also revealed that the weave form had a bigger impact on the fabric's force at rupture. Plain weave has the largest tensile force, as expected, because it contains the most interlacing points, resulting in higher friction between yarns and, as a result, higher tensile strength. Figures 3 and 4 illustrate that twill and satin weaves have lower values. The filling and warp breaking forces rise as the number of filling and warp strands per inch increases. It's due to the increased breaking strength of the cloths as a result of the increased number of yarn interlacing. In both weaves, the warp breaking strength decreases marginally as the number of filling yarns per inch increases. The decrease is due to loom abrasion of the warp yarns, which rises in direct proportion to the amount of filling yarns per inch. The breaking strength of the yarns in the cloth is reduced by loom abrasion. Since the actions of the loom are directly proportional to the number of filling yarns per inch, the decrease is proportional to the amount of loom abrasion, or the number of filling yarns per inch.

Figure 5 illustrates the force at rupture in a weft way. The initial rupture force for a 100 × 60 plain fabric with a 3.8 twist multiplier was 630.9 N, and it rose as the twist multiplier value climbed, reaching 624.44 N for a 4.2 twist multiplier value. The 95 × 50 twill and 90 × 55 twill fabrics followed a similar trend in terms of rupture force. In a similar way to plain and twill fabrics, the rupture force of 100 × 60 satin, 95 × 50 satin, and 90 × 55 satin increased.

Elongation of the fabric was calculated in both the warp and weft directions. Fabric elongation is affected by the twist multiplier. Fabric elongation increases proportionally as the twist multiplier increases in both the warp and weft way directions. Plain weave has the most elongation, while twill weave has a medium elongation and satin weave has the least. The elongation in the warp way direction is depicted in Figure 5.

Initial value of elongation percentage for a 100 × 60 plain fabric was 22 percent for a 3.8 twist multiplier, and it increased as the twist multiplier value increased, reaching 25.1 percent for a 4.2 twist
Figure 3. Force at rupture at greige state (warp way).
multiplier value. In the case of $95 \times 50$ plain fabric and $90 \times 55$ plain fabric, the elongation value followed a nearly identical pattern. The initial value of elongation percentage for a $100 \times 60$ twill fabric was 18.2 percent for a 3.8 twist multiplier, and it was seen to rise with the increase of twist multiplier value, hitting nearly 20% for a 4.2 twist multiplier value. In the case of $95 \times 50$ twill cloth, the elongation value followed a similar pattern as $100 \times 60$ twill fabric. While the elongation percentage increased with the increase of twist multiplier in the case of $90 \times 55$ twill cloth, there was a substantial difference between the elongation percentage of twist multipliers 4.0 and 4.2, which was not seen previously. The elongation percentage for $90 \times 55$ twill fabric was 16.2 percent with a 4.0 twist multiplier and nearly 20% with a 4.2 multiplier. The elongation of $100 \times 60$ satin, $95 \times 50$ satin, and $90 \times 55$ satin increased in a nearly identical manner as the twist multiplier was increased.

Figure 6 depicts the elongation at maximum force at greige state in the weft way direction. The percentage of weft way elongation appears to
be lower than the percentage of warp way elongation. The percentage of weft way elongation followed the same pattern as the warp way path. For a 100/C260 plain fabric with a 3.8 twist multiplier, the initial value of elongation percentage was 12.1 percent, and it rose as the twist multiplier value increased, reaching 13.8 percent with a 4.2 twist multiplier value. The elongation value of 95/C250 plain fabric followed a virtually similar pattern as before. In the case of 90/C255 plain cloth, the elongation percentage values were almost identical (nearly 11%) for 3.8 and 4.0 twist multipliers, but substantially improved for 4.2 twist multiplier, reaching 13 percent. For a 100/C260 twill fabric, the initial value of elongation percentage was 10.9 percent for a 3.8 twist multiplier, and it was seen to grow with the increase of twist multiplier value, reaching 12.6 percent for a 4.2 twist multiplier value. The 95/C250 twill fabric and the 90/C255 twill fabric had a trend that was almost identical. As the twist multiplier was raised, the elongation of 100/C260 satin, 95/C250 satin, and 90/C255 satin increased in a nearly similar manner.

The crimp of the fabric has a significant effect on elongation. The longer the fabric can stretch, the more crimp it has in its structure. Fabric crimp can be affected by the number of interlacement points in the structure. With more interlacement points, additional crimp is possible. Plain weave produces the most crimp and has the highest elongation value because it has more interlacement points than twill and satin weave. Twill weave has higher interlacement points than satin weave and lower interlacement points than plain weave. Satin weave has the smallest crimp and elongation value because it has the smallest interlacement points. On the other hand, an increased twist multiplier value indicates an increase in the number of turns per unit length of yarn. As the number of turns per unit length increases, so does the elasticity of the yarn. With a greater number of turns, the yarn can extend further, resulting in a higher elongation value. The fabric elongation value increased as the TM value increased from 3.8 to 4.2. As a result, as the TM value increased from 3.8 to 4.2, so did the fabric elongation value. However, the TM value of the yarn has impact on the comfort properties of the fabric. With an increase in the twist factor of the yarn, the actual insulation and thermal resistance properties dropped. Air and water permeability (penetration) increases as the yarn twist level increases. Because of the hairy yarns, which minimize porosity in the woven fabrics, the air and water permeability of cotton fabrics with low twist yarns is reduced. As a result, the fabric pores close and the air and water permeability is reduced. Similarly, fabrics constructed from high-twist yarns, meanwhile, had a less hairy surface and a more porous structure, resulting in greater water permeability. The thermal conductivity increased as the twist level increased. Higher twist opens up more spaces in the fabric, resulting in higher conductivity via convection and radiation. Higher TM values, on the other hand, result in lower wickability and absorbency due to a reduction in hairy fibers on the yarn surface. Twist level has also impact on fabric strength. As the twist level rises, the tensile and shear characteristics of the fabric likewise increase. This occurred because with more turns per metre, the yarns became denser and more strong [53, 54, 55].

3.3. Force at rupture after desizing, scouring and bleaching

The force at rupture was seen to decrease at both warp and weft way after the desizing, scouring and bleaching. In Figure 7, the total reduction percentage was higher in the weft direction than in the warp direction. The graph shows that warp way reduction percentages for plain, twill, and satin vary from 3-18 percent, 4–29 percent, and 5–14 percent, respectively, while weft way reduction percentages for plain, twill, and satin range from 14-30 percent, 10–47 percent, and 17–30 percent, respectively. Rupture force decreases in the warp direction after desizing, scouring, and bleaching, which can be due to the removal of sizing material from the surface. Twill fabric with 3.8 TM and 90 × 55 thread density showed the highest reduction in both the warp and weft way while plain fabric with 4.2 TM and 100 × 60 thread density showed the lowest reduction in both the warp and weft way. The loss of strength and elasticity of cellulosic fibers caused by scouring and bleaching is thought to be the cause of the observed decrease in force at rupture.

![Figure 6. Elongation at maximum force at greige state (Weft way).](image-url)
3.4. Elongation at maximum force after desizing, scouring and bleaching

The percentage of warp way elongation was reduced and the percentage of weft way elongation was increased after desizing, scouring, andbleaching, compared to their greige state. Figure 8 shows the percentages of warp way elongation reduction and weft way elongation rise. The graph shows that warp way reduction percentages for plain, twill, and satin vary from 54-68 percent, 38–55 percent, and 32–64 percent, respectively, while weft way increase percentages for plain, twill, and satin range from 32-52 percent, 25–45 percent, and 22–48 percent, respectively. Elongation decreases in the warp direction after desizing, scouring, and bleaching, which can be due to the removal of size from the surface, but there is an unusual increase in elongation at break in the weft direction.

Cotton fiber’s functional group is vulnerable to oxidizing reagents. Raw cotton fibers are treated with oxidizing reagents such as H₂O₂ during the bleaching process. These reagents produce a chemical attack (oxidation) on the functional groups first, followed by chain scission, lowering the DP and, almost invariably, lowering the tensile strength and elongation of the fibers.

3.5. Regression analysis

The cause-effect relationship between two variables, Y dependent and X independent variables, is discovered using regression analysis utilizing the stepwise technique. Rapture force and elongation were treated as dependent variables, while yarn density and TM were treated as independent variables. The dependent variables were the average value of rapture force and elongation in both the warp and weft directions. Regression model was applied separately to assess the rapture force and elongation of plain, twill and satin structure. Following these steps, regression analysis is used to explain the relationship between dependent and independent variables. In “ANOVA table”, significance value obtained as less than 0.01 and that means model is meaningful.
3.6. Elongation at maximum force

All independent variables projected to affect the elongation at maximum force value were included in the analysis. All three fabric structures had P-values of less than 0.05 for TM, warp density, and weft density, indicating that all three parameters contribute significantly to elongation at maximum force (Tables 5, 6, and 7). The adjusted R² value of the model was found to be near 0.90, as shown in the model summary, which suggests that these parameters explain about 90% of the elongation value of plain, twill, and satin cloth. The adjusted R² indicates that the model’s predictive power is adequate. From the regression analysis the equation of elongation at maximum force for plain twill and satin fabrics have been derived which are shown as below:

\[ E = 5.7P + 0.1518Q - 0.0422R - 11.5244 \]  
\[ (i) \]

\[ E = 6.217P + 0.115Q + 0.099R - 23.533 \]  
\[ (ii) \]

\[ E = 2.542P + 0.122Q + 0.179R - 19.814 \]  
\[ (iii) \]

\[ E = 4.442P + 0.054Q - 0.014R - 11.5244 \]  
\[ (iv) \]

\[ E = 4.058P - 0.019Q + 0.072R - 10.301 \]  
\[ (v) \]

\[ E = 4.708P - 0.019Q - 0.072R - 10.767 \]  
\[ (vi) \]

\[ E = \text{Elongation at maximum force}, \text{P} = \text{Twist multiplier}, \text{Q} = \text{Warp density}, \text{R} = \text{Weft density}. \text{where}, \]

(i) Elongation at maximum force at warp way for plain weave
(ii) Elongation at maximum force at warp way for twill weave
(iii) Elongation at maximum force at weft way for satin weave
(iv) Elongation at maximum force at weft way for plain weave

3.7. Rapture force

Analysis was started with all independent variables predicted to affect the rapture force value. P-values of TM, warp density and weft density were less than 0.05 for all three fabric structures which means all three parameters have significant contribution to rapture force (Tables 8, 9, and 10). The adjusted R² value of the model was found to be near about 0.90 which is shown in model summary that means nearly 90% of the rapture force value of plain, twill and satin fabric is explained by these parameters. Adjusted R² show that the predictive power of the model is high enough. From the regression analysis the equation of rapture force for plain twill and satin fabrics have been derived which are shown as below:

\[ F = 43.592P + 4.986Q + 5.112R - 319.616 \]  
\[ (vii) \]

\[ F = 48.533P + 4.729Q - 1.951R - 169.43 \]  
\[ (viii) \]

\[ F = 37.658P - 0.722Q + 5.929R + 133.94 \]  
\[ (ix) \]

\[ F = 14.875P + 6.043Q - 0.078R - 289.201 \]  
\[ (x) \]

\[ F = 37.258P + 4.966Q + 0.214R - 307.762 \]  
\[ (xi) \]

\[ F = 57.208P + 6.234Q - 1.193R - 447.32 \]  
\[ (xii) \]

\[ F = \text{Force at rapture}, \text{P} = \text{Twist multiplier}, \text{Q} = \text{Warp density}, \text{R} = \text{Weft density}. \text{where}, \]

(vii) Rapture force at warp way for plain weave
(viii) Rapture force at weft way for plain weave
(ix) Rapture force at warp way for twill weave
(x) Rapture force at weft way for twill weave
(xi) Rapture force at warp way for satin weave
(xii) Rapture force at weft way for satin weave

Table 5. Regression analysis for elongation percentage of plain weave.

|             | R Square | Adjusted R Square | Standard Error | Observations |
|-------------|----------|-------------------|----------------|--------------|
|             | 0.929    | 0.887             | 0.374          | 9            |

ANOVA

| df | SS   | MS   | F    | Significance F |
|----|------|------|------|---------------|
| Regression | 3    | 9.202| 3.067| 21.915        |
| Residual   | 5    | 0.700| 0.140|              |
| Total      | 8    | 9.902|      | 0.003         |

Table 6. Regression analysis for elongation percentage of twill weave.

|             | R Square | Adjusted R Square | Standard Error | Observations |
|-------------|----------|-------------------|----------------|--------------|
|             | 0.972    | 0.901             | 0.576          | 9            |

ANOVA

| df | SS   | MS   | F    | Significance F |
|----|------|------|------|---------------|
| Regression | 3    | 9.339| 3.113| 3.98          |
| Residual   | 5    | 1.656| 0.331|              |
| Total      | 8    | 10.995|      | 0.007         |

Table 7. Regression analysis for elongation percentage of satin weave.

|             | R Square | Adjusted R Square | Standard Error | Observations |
|-------------|----------|-------------------|----------------|--------------|
|             | 0.950    | 0.921             | 0.268          | 9            |

ANOVA

| df | SS   | MS   | F    | Significance F |
|----|------|------|------|---------------|
| Regression | 3    | 6.870| 2.290| 31.998        |
| Residual   | 5    | 0.358| 0.072|              |
| Total      | 8    | 7.228|      | 0.001         |

Table 8. Regression analysis for rapture force of plain weave.

|             | R Square | Adjusted R Square | Standard Error | Observations |
|-------------|----------|-------------------|----------------|--------------|
|             | 0.962    | 0.893             | 13.03          | 9            |

ANOVA

| df | SS   | MS   | F    | Significance F |
|----|------|------|------|---------------|
| Regression | 3    | 7798.512| 2999.504| 15.310        |
| Residual   | 5    | 848.935| 169.787|              |
| Total      | 8    | 8647.447|      | 0.006         |

Table 9. Regression analysis for rapture force of twill weave.

|             | R Square | Adjusted R Square | Standard Error | Observations |
|-------------|----------|-------------------|----------------|--------------|
|             | 0.950    | 0.921             | 0.268          | 9            |

ANOVA

| df | SS   | MS   | F    | Significance F |
|----|------|------|------|---------------|
| Regression | 3    | 6.870| 2.290| 31.998        |
| Residual   | 5    | 0.358| 0.072|              |
| Total      | 8    | 7.228|      | 0.001         |

Table 10. Regression analysis for rapture force of satin weave.

|             | R Square | Adjusted R Square | Standard Error | Observations |
|-------------|----------|-------------------|----------------|--------------|
|             | 0.950    | 0.921             | 0.268          | 9            |

ANOVA

| df | SS   | MS   | F    | Significance F |
|----|------|------|------|---------------|
| Regression | 3    | 6.870| 2.290| 31.998        |
| Residual   | 5    | 0.358| 0.072|              |
| Total      | 8    | 7.228|      | 0.001         |

9
3.8. Comparison between siro spun fabric and ring spun fabric

To investigate the comparison of elongation and rapture force between siro spun fabric and ring spun fabric, a master sample was developed with specification of 25/1 Tex, 50/50 cotton–tencel, 100 × 60 yarn density, TM = 4, plain structure. This master sample was compared to the same specification siro spun 50/50 cotton-tencel fabric.

Comparison between ring spun fabric and siro spun fabric in terms of elongation and rapture force is shown in Figures 9 and 10. Siro spun fabric has a 9–13% higher elongation (Figure 9) and a 11–15% higher rapture force than that of ring spun fabric (Figure 10). The strength fluctuation caused by unevenness in the fiber. The hairs surrounding the yarn axis are spun onto the yarn surface, which improves yarn density and reduces unevenness, resulting in increased elongation and strength. The packing density of siro yarns is higher than that of ring yarns, which is one of the factors contributing to the increased strength of siro yarns. Siro yarn has increased fiber migration, increased spinning coefficient, improved straight fiber ratio, less yarn breakage and low hairiness. Yarn migration parameters include yarn mean, migration factor, packing density, migration index, standard deviation and migration amplitude. Higher migration criteria are also responsible for the increased strength and elongation of the siro yarn.

4. Conclusion

A 50/50 cotton-tencel siro spun woven fabric has greater strength and elongation than a 100% cotton ring spun woven fabric. The tensile qualities of a 50/50 cotton-tencel woven fabric are influenced by the twist multiplier and the fabric structure. Plain weaves have more elongation and breaking strength than twill or satin weaves. The twist multiplier enhanced the breaking strength proportionately. Elongation at maximum force is proportional to the twist multiplier. For twist multipliers of 3.8, 4.0, and 4.2, the elongation rose as the twist multiplier increased. Overall, the warp way direction had higher elongation and breaking strength than the weft way direction. Sizing chemical gives warp yarn more strength and elasticity, resulting in greater elongation and breaking strength in the warp direction.

Declarations

Author contribution statement

Farhana Afroz: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.
Momtaz Islam: Analyzed and interpreted the data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.
Data availability statement
Data will be made available on request.

Declaration of interests statement
The authors declare no conflict of interest.

Additional information
No additional information is available for this paper.

Acknowledgement
The authors wish to express their heartfelt gratitude to the Department of Textile Manufacturing Engineering, Bangladesh University of Textiles, Dhaka, Bangladesh, for allowing them to manufacture the fabrics and conduct the various tests.

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