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Investigating Tear Strength in Sustainable Cotton-Lyocell Blend Siro Spun Fabrics: Twist Multiplier and Weave Type Effects

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Article

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ABSTRACT

This study investigates the tear strength properties of a cotton-Lyocell blend siro spun fabric. Lyocell fibre production follows sustainable practices with a closed-loop system and renewable resources, requiring less energy and water. Furthermore, Lyocell is a biodegradable fibre, ensuring its environmentally friendly decomposition. Similarly, cotton offers durability, washability and biodegradability, making it an eco-conscious fabric alternative. Woven fabrics were created using cotton-Lyocell blend siro spun yarns with varying twist multipliers and thread densities in plain, twill and satin weaves. The tear strength of these fabrics was measured and regression analysis was conducted to investigate the impact of different parameters. The results demonstrate that twist multiplier, warp density and weft density significantly affect the tear strength of all fabric types. Furthermore, a comparison was made between the tear strength of the cotton-Lyocell siro spun fabrics and conventional ring-spun cotton fabrics and found that cotton-lyocell siro spun fabrics offer better strength properties compared to conventional ring-spun cotton fabrics. The findings of this study provide valuable insights into fabric strength factors, contributing to future research in textile development for enhanced durability and sustainability.

KEYWORDS

tear strength, cotton, lyocell, siro spun fabric

INTRODUCTION

Regenerated cellulosic fibres combine the advantages of natural and synthetic fibres, making them ideal for various textile and nonwoven uses. Lyocell is one of the most popular regenerated cellulosic fibres which is claimed as “green and eco-friendly fibre” with a good application prospect [1]. Derived from renewable sources like wood pulp, lyocell's production process is environmentally friendly, utilizing a closed-loop system that minimizes waste and emissions. It requires less energy and water compared to other fibres, making it highly resource-efficient [2]. Studies have revealed that Lyocell fibres possess enhanced antimicrobial properties, effectively combatting various bacteria and fungi

[3]. Additionally, lyocell is biodegradable, ensuring its safe return to nature [4]. With its durability and versatility, lyocell products have a longer lifespan [5]. All these factors collectively make lyocell an appealing choice for sustainable textile option. In addition, cotton is a widely used natural fibre consisting of mostly cellulose with minor amounts of hemicellulose, lignin, ash and moisture (Table 1). It is durability, biodegradability and recyclability make it a unique choice for an environment-friendly option.

Table 1. Properties of lyocell and cotton fibre

	Content (%)	
Property	**Lyocell**	**Cotton**
Moisture	9.3± 0.1	5.3±0.1
Ash	0.9 ± 0.1	1.3±0.1
Cellulose	97.5 ± 0.3	96±0.3
Hemicellulose	0.5 ±0.2	0.3±0.1
Lignin	0.0	0.0

There are different ways of combining different fibres to make yarn to take advantage of their identical properties. Modern textile manufacturers frequently combine viscose, modal and lyocell fibres because the resulting textiles are soft and durable. A study looked at the properties of cotton-lyocell blends using different spinning methods. Overall, the results show that the blends are very soft and comfortable to wear [6,7]. In addition, they show good resistance to drapes and wrinkles [8]. Based on different spinning processes, Kilic and Suler investigated the effect of the spinning system on the yarn quality, mechanical properties and manufacturing process of cotton and Lyocell yarns [9]. Various spinning systems offer fundamental changes to the standard ring spinning process, which has been extensively studied over the past two decades. They found that siro-spun yarn has excellent mechanical properties [10-14]. Siro yarn is made by spinning two parallel rovings and twisting them together. To a certain extent, it is constructed on the principle of self-twisting [15]. Figure 1 shows the components of siro spinning. Siro spun yarn typically has higher tensile strength compared to conventional spun yarn. This is because the siro spinning technique allows for better alignment and intermingling of fibres, resulting in a more cohesive and stronger yarn [16]. Siro spinning helps in achieving better yarn evenness and reduces variations in yarn thickness. The technique ensures a consistent twist level and fibre distribution, leading to a more uniform yarn appearance and improved fabric quality [17]. Siro spun yarn tends to have lower hairiness compared to other spun yarn types. Hairiness refers to the presence of protruding fibers on the surface of the yarn. The siro spinning technique helps to minimize fiber protrusion, resulting in a smoother and cleaner yarn surface [18]. The improved fibre alignment and reduced hairiness in siro spun yarn contribute to better dye uptake during the dyeing process. This results in improved colour vibrancy and colourfastness in the final fabric [19]. Siro spinning enables higher production rates due to its ability to combine multiple fibres into a single yarn during the spinning process. This reduces the number of spinning processes required, resulting in increased efficiency and productivity in yarn manufacturing [20]. Furthermore, Siro spun yarn can be manufactured using various types of fibre, including synthetic fibres like polyester, nylon, lyocell, acrylic and rayon as well as natural fibers like cotton and wool. Due to this versatility, siro spun yarns have a great potential for applications in a wide variety of industries, ranging from furnishings and fashionable clothing to protective clothing and technical textiles [21]. Solo spinning is another advanced technique of yarn spinning. To make a solo-spun, an additional, smaller roller is attached to the spinning frame which rotates with the main bottom roller. This creates new roller slots, which alternate around the edge of the ball. This results in the ball having many smaller strands, all of which have a fixed shape. This makes the solo-spun process better at trapping fibres [22]. Solo-spun is a type of spinneret that is specially designed for wool but can also be used for other manufactured fibres. It has a greater drafting capacity than siro spun, which makes it suitable for spinning long, dense fibres [23]. However, solo-spun does not seem to be usable for cotton, which is likely because the finer and more compact cotton strands are harder to separate into sub-strands. Solo-spun is formulated specifically for wool and can be used on 100% synthetic fibres, such as wool and wool/synthetic fiber blends. It also works well with other animal fibers, including cashmere and other fibers with long staples. Yuzheng and Yang claimed that siro-spinning yarns are stronger than those spun with a conventional spinning process [24]. Mezarcöz et al. investigated that compact-siro spinning can improve energy distribution in yarns, making them more elastic and fast-growing. Because the pile fibers are tightly wrapped during the spinning process, siro spinning results in a fabric that is more resistant to wear and tear. This decreases the amount of yarn that needs to be separated, which results in an increase in the fabric's resistance to snarling [25]. The properties of a fabric are not solely determined by the characteristics of its yarn but are also influenced by its construction factors such as war yarn density, weft yarn density weave type etc. Different fabric construction results in different mechanical properties although the yarn characteristics are the same [26,27]. It is reported in the literature that the plain-woven fabric has higher strength than the 2/1 twill and twill 2/2 twill fabrics. The study showed that warp way plain has greater strength than warp way twill and weft way plain has greater strength than weft way twill [28,29]. The fabric strength changes as the interlacing point increases and this has not been studied in detail. However, only a few researchers studied the crossing-over factor (COF) and floating yarn factor to estimate the mechanical properties (strength and stiffness) of various woven fabrics and it was found that the weft way tensile strength of a plain weave is about three times that of a twill weave and both the crossing over factor (COF) and the floating yarn factor were found to be important in predicting the mechanical properties of a fabric [30]. Textile fabrics are made from materials that resist changes in their shape when subjected to external forces. This is determined by the mechanical properties of the material, how it is loaded and how tight the fabric is. Designers and manufacturers need to know how a textile material responds to being stretched or compressed [31]. Among all the mechanical properties of textile material, tear strength is very crucial because tear resistance measures a fabric's ability to resist tearing or ripping when subjected to stress or mechanical forces. Fabric with high tear resistance contributes to durability. This is particularly important for fabrics used in applications which require strength and longevity, such as upholstery, outdoor gear, workwear and industrial textiles [32]. Tear resistance is directly linked to the safety of individuals using or wearing textile products. For example, in protective clothing or equipment [33]. Moreover, tear resistance is essential for fabrics used in various demanding applications. Sports apparel, for instance, needs to withstand the stress and strain associated with intense physical activities [34]. High tear resistance ensures that the fabric can withstand stretching, pulling, or snagging during athletic movements without tearing, maintaining its structural integrity and performance [35]. Fabrics with good tear resistance tend to have a longer lifespan. Additionally, tear-resistant fabrics can withstand rigorous cleaning processes without significant damage, extending their usable life [36]. Tear resistance can also contribute to the appearance and quality of textile products. Fabrics that resist tearing tend to maintain their shape and integrity, preventing unsightly rips or fraying that could diminish the overall aesthetics of the item. This is particularly important for high-end or luxury fabrics used in fashion and interior design, where durability and a polished appearance are desired [37,38]. For a sustainable textile product, mechanical properties are equally important along with their physical properties. In terms of physical properties, lyocell exhibits some unique characteristics including softness, moisture absorption, thermal regulation, lightweight, wrinkle resistance and biodegradability. Following that regenerated fiber such as lyocells are essentially being considered a potential substitute for cotton because of their increasing price and limited availability [39]. Although, a vast research has been conducted on the physical properties of cotton lyocell blend fabric there is a very limited research work has been done on the mechanical properties of cotton lyocell blended siro spun woven fabric. Mechanical properties of fabric depend on several factors related to yarn and fabric construction. Yarn twist multiplier and fabric structure are one of the most important factors among them. The twist multiplier provides a standardized measure of the twist level relative to the linear density of the yarn. It helps in comparing and specifying the twist of different yarns, especially when considering their suitability for specific applications or fabric constructions. A higher twist multiplier results in increased yarn cohesion and improved fabric strength [40,41]. On the other hand, the fabric structure also influences the flexibility and strength. Densely woven fabric with tighter interlacing contributes to improved strength and resistance to deformation and stretching and exhibits better dimensional stability [42]. Therefore, it is important to know the impact of yarn twist multiplier and fabric structure on the tear strength of cotton lyocell blend siro spun woven fabric.

In this study, we have investigated the tear resistance property of cotton-lyocell blend (50:50) woven fabric. Woven fabrics with plain, twill and satin structures were developed using cotton-lyocell blend yarns with three different twist multipliers and three different yarn densities. The impact of the twist multiplier and the fabric construction factors such as warp yarn density, weft yarn density weave type etc on tearing strength was thoroughly investigated. By considering the optimal combination of twist multiplier and fabric structure, manufacturers can achieve a fabric with the desired mechanical properties for specific applications, balancing strength, flexibility and durability which will help facilitate product diversification to meet consumer demand.

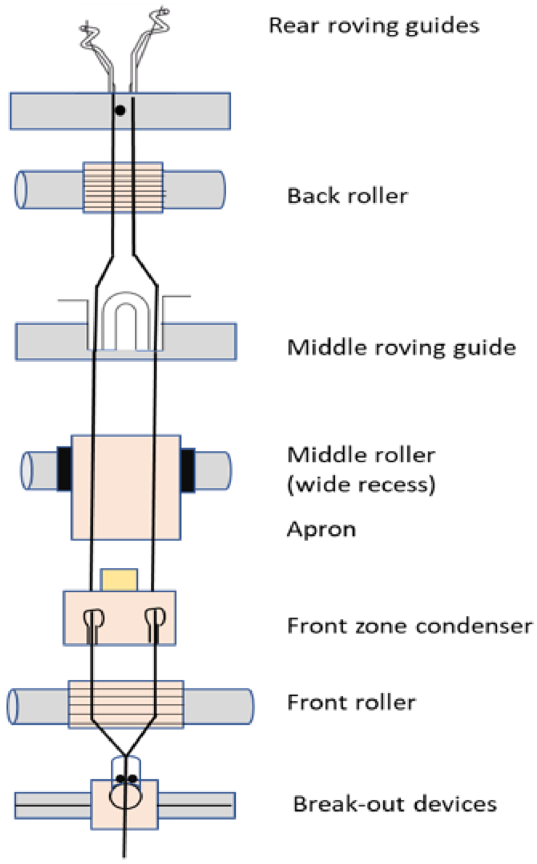


Figure 1. Siro spinning components

EXPERIMENTAL

Materials

Prior study has indicated that a 50/50 blend of cotton and Tencel yields favourable results in terms of specific properties or performance metrics [43]. Therefore, a blend of 50% cotton and 50% Lyocell was used to construct the fabric. 25/1 tex warp and weft yarn counts were spun with three different twist multipliers: 3.8, 4.0 and 4.2. A variety of chemicals were used for sizing, scouring and bleaching, which were bought from Huntsman, Singapore and applied without modification. All of the yarns were made using the siro spinning method. According to the spinning procedure, the physical properties of the yarns are provided in Table 2-4. The characteristics of the yarns are compared in Figures 2 (a- d). The yarns' unevenness (U per cent) ranges from 10 to 11 (Figure 2a), whereas the hairiness value was found around five (Figure 2 b). The yarn with TM value 4 had the highest thin place value, whereas thick place and neps content were practically identical for all.

Table 2. The yarn test result of 25/1 Tex, 3.8 TM yarn

Sl No	U%	Hairiness (above 3mm/10m)	Thin -30%/km	Thick 50%/km	Neps 200%/km	Elongation (%)	Tenacity g/denier
1	9.35	6.0	937.5	230.0	217.5	11.2	5.35
2	9.55	5.0	857.5	210.5	225.0	11.6	5.28
3	9.57	4.0	910.0	162.5	187.5	11.7	5.32
4	9.15	8.0	887.5	195.0	235.5	11.3	5.29
5	9.16	5.0	1025.0	250.5	222.0	11.4	5.33
6	9.40	4.0	887.4	205.0	300.5	11.8	5.27
7	9.26	6.0	1025.5	232.5	275.0	11.1	5.34
8	9.20	3.0	795.5	196.5	216.0	11.9	5.26
9	9.44	5.0	898.6	255.0	267.5	11.5	5.31
10	10.18	6.0	1080.5	290.5	365.5	11.0	5.30
Mean	9.43	5.20	930.5	222.8	251.2	11.45	5.31
SD	0.30	1.40	87.69	36.67	52.22	0.29	0.03
CV%	3.23	26.89	9.42	16.46	20.79	0.03	0.01
Max	10.18	8.0	1080.5	290.5	365.5	11.9	5.35
Min	9.15	3.0	795.5	162.5	187.5	11.0	5.26

Table 3. The 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	Elongation (%)	Tenacity g/denier
1	10.28	4.0	1195.0	200.5	212.5	12.3	5.8
2	10.65	6.0	995.0	225.5	255.0	12.0	6.0
3	9.77	5.0	1101.0	197.0	245.5	11.8	5.7
4	10.44	7.0	920.0	210.0	210.0	12.5	6.1
5	10.18	5.0	967.0	201.3	265.0	12.1	5.9
6	10.25	4.0	1015.0	245.0	267.0	11.9	5.8
7	10.14	7.0	975.0	218.5	215.0	12.2	5.7

Sl No	U%	Hairiness (above 3mm/10m)	Thin -30%/km	Thick 50%/km	Neps 200%/km	Elongation (%)	Tenacity g/denier
8	11.28	6.0	1130.0	222.0	310.0	12.4	6.2
9	11.45	4.0	1145.0	235.7	254.0	12.0	5.8
10	11.12	5.0	1085.0	235.5	220.0	12.2	6.0
Mean	10.56	5.3	1052.8	219.1	245.4	12.14	5.90
SD	0.55	1.16	90.59	16.66	31.79	0.21	0.16
CV%	5.25	21.88	8.60	7.61	12.95	0.02	0.03
Max	11.45	7.0	1195.0	245.0	310.0	12.5	6.20
Min	9.77	4.0	920.0	197.0	210.0	11.8	5.70

Table 4. The 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	Elongation (%)	Tenacity g/denier
1	10.19	7.0	859.95	200.6	189.25	12.80	6.4
2	10.10	6.0	839.95	245.6	271.75	12.70	6.3
3	10.95	5.0	934.95	273.1	241.75	12.79	6.2
4	11.18	4.0	1029.95	230.6	241.75	12.75	6.4
5	10.15	8.0	875.50	243.1	269.25	12.76	6.3
6	10.52	5.0	892.45	183.1	211.75	12.78	6.4
7	10.15	3.0	924.95	220.6	219.25	12.74	6.2
8	11.05	6.0	1007.50	278.1	279.25	12.76	6.35
9	10.55	5.0	995.80	165.6	206.75	12.79	6.36
10	10.65	6.0	1034.50	213.1	199.25	12.78	6.34
Mean	10.55	5.50	939.55	225.35	233,00	12.77	6.33
SD	0.39	1.43	72.86	36.45	32.47	0.03	0.07
CV%	3.73	26.07	7.76	16.17	13.94	0.00	0.01
Max	11.18	8.0	1034.50	278.1	279.25	12.80	6.40
Min	10.10	3.0	839.95	165.6	189.25	12.70	6.20

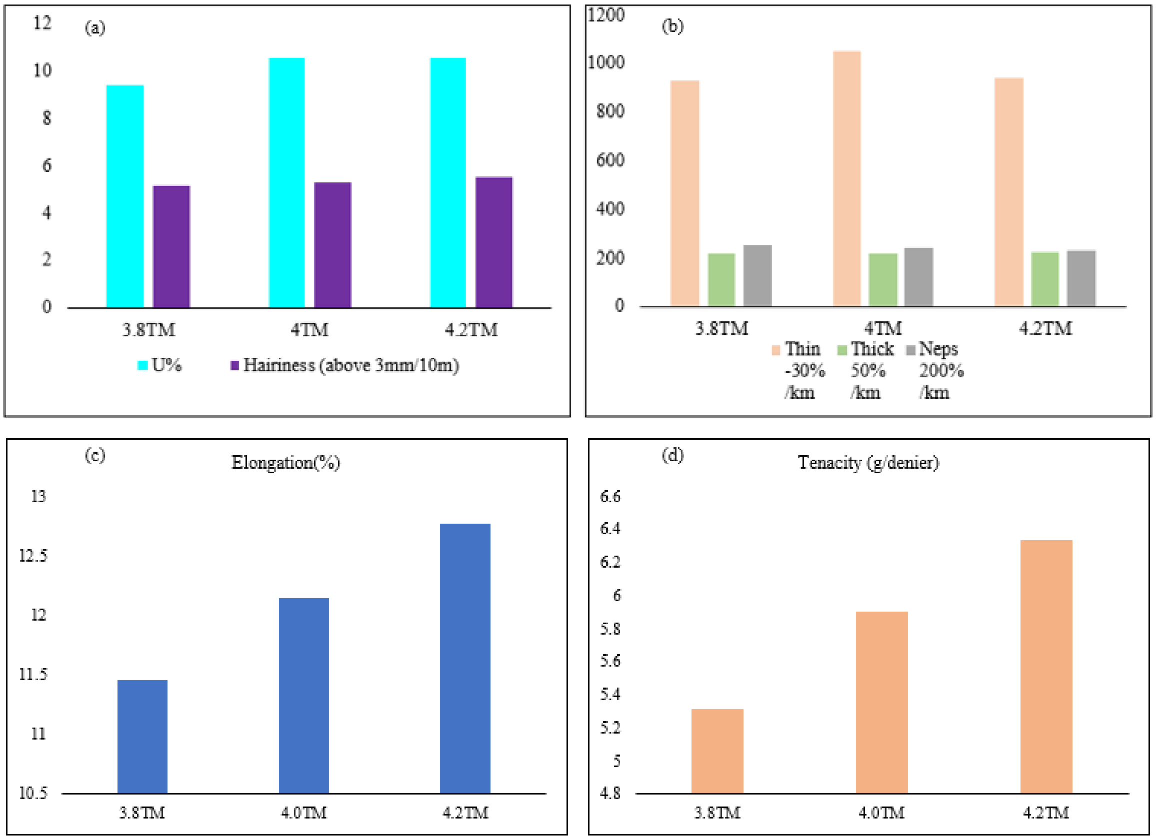


Figure 2. Physical properties of yarn (a) U% and hairiness value (b) thick place, thin place and neps content (c) elongation (%) (d) tenacity (g/denier)

Sample preparation

A miniature air-jet weaving machine was used to weave all of the fabric samples. Woven fabrics are commonly found in our everyday lives and are constructed by interlacing two sets of yarns at right angles. Several basic woven fabric structures vary in their appearance, properties and intended applications [44]. One fundamental structure is plain weave, where the warp and weft yarns alternate over and under each other, resulting in a balanced, simple crisscross pattern. Twill weave, another widely used structure, creates diagonal lines on the fabric surface by allowing the weft yarns to float over multiple warp yarns. Satin weave is characterized by long floats, as the weft yarns pass over several warp yarns before going under one, producing a lustrous, smooth fabric [45]. Each of these basic woven fabric structures offers unique properties, textures and aesthetics, catering to a wide range of applications in the fashion, upholstery and industrial sectors [46].

Therefore, samples were prepared based on three basic woven structures: 1/1 plain, 2/2 twill and 5-end satin (Figure 3). We used three different warp and weft densities to construct the fabrics. The number of warp yarn per inch was considered 100, 95 and 90 while the number of weft yarn per inch was considered 60, 55 and 50. Yarns with a 25/1tex count were used in both the warp (along the length of the fabric) and weft (along the width of the fabric) directions. These yarn densities were chosen because they are the most regularly utilized in the industry for fabric manufacture. Table 5 summarizes the features of woven fabric samples.

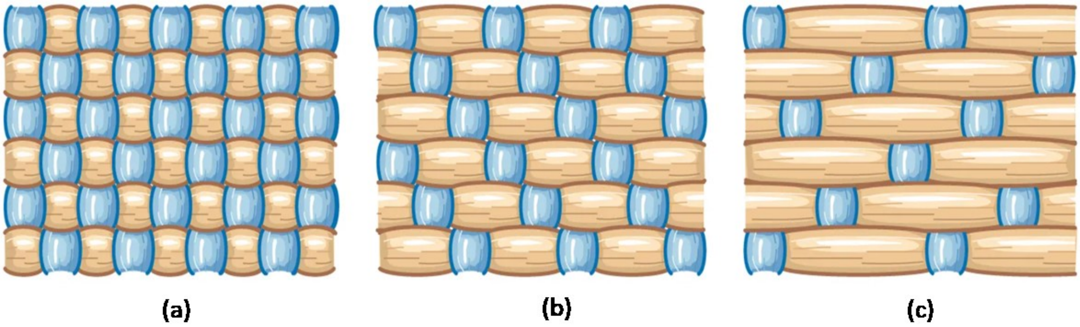


Figure 3. Woven fabric architectures: (a) plain, (b) twill, (c) satin [47]

Table 5. Yarn and fabric specifications in detail

No. of sample	Twist multiplier of yarn (mean value)	Standard deviation of twist multiplier	Warp and weft count (mean value)	Standard deviation of yarn count	Woven fabric structure	EPI X PPI
1	3.8	0.245	25/1 Tex	0.049	1/1 Plain	100x60
2	4	0.082	25/1 Tex	0.024	1/1 Plain	100x60
3	4.2	0.024	25/1 Tex	0.098	1/1 Plain	100x60
4	3.8	0.098	25/1 Tex	0.106	2/2 Twill	100x60
5	4	0.041	25/1 Tex	0.09	2/2 Twill	100x60
6	4.2	0.082	25/1 Tex	0.065	2/2 Twill	100x60
7	3.8	0.082	25/1 Tex	0.016	5 end satin	100x60
8	4	0.057	25/1 Tex	0.808	5 end satin	100x60
9	4.2	0.041	25/1 Tex	0.8	5 end satin	100x60
10	3.8	0.057	25/1 Tex	0.792	1/1 Plain	90x55
11	4	0.041	25/1 Tex	0.784	1/1 Plain	90x55
12	4.2	0.082	25/1 Tex	0.033	1/1 Plain	90x55
13	3.8	0.098	25/1 Tex	0.049	2/2 Twill	90x55
14	4	0.408	25/1 Tex	0.057	2/2 Twill	90x55
15	4.2	0.065	25/1 Tex	0.065	2/2 Twill	90x55
16	3.8	0.065	25/1 Tex	0.09	5 end Satin	90x55
17	4	0.049	25/1 Tex	0.098	5 end Satin	90x55
18	4.2	0.073	25/1 Tex	0.106	5 end Satin	90x55
19	3.8	0.024	25/1 Tex	0.114	1/1 Plain	95x50
20	4	0.016	25/1 Tex	0.131	1/1 Plain	95x50
21	4.2	0.082	25/1 Tex	0.082	1/1 Plain	95x50

No. of sample	Twist multiplier of yarn (mean value)	Standard deviation of twist multiplier	Warp and weft count (mean value)	Standard deviation of yarn count	Woven fabric structure	EPI X PPI
22	3.8	0.041	25/1 Tex	0.073	2/2 Twill	95x50
23	4	0.057	25/1 Tex	0.065	2/2 Twill	95x50
24	4.2	0.041	25/1 Tex	0.057	2/2 Twill	95x50
25	3.8	0.065	25/1 Tex	0.057	5 end Satin	95x50
26	4	0.082	25/1 Tex	0.049	5 end Satin	95x50
27	4.2	0.073	25/1 Tex	0.041	5 end Satin	95x50

Measurement of tearing strength

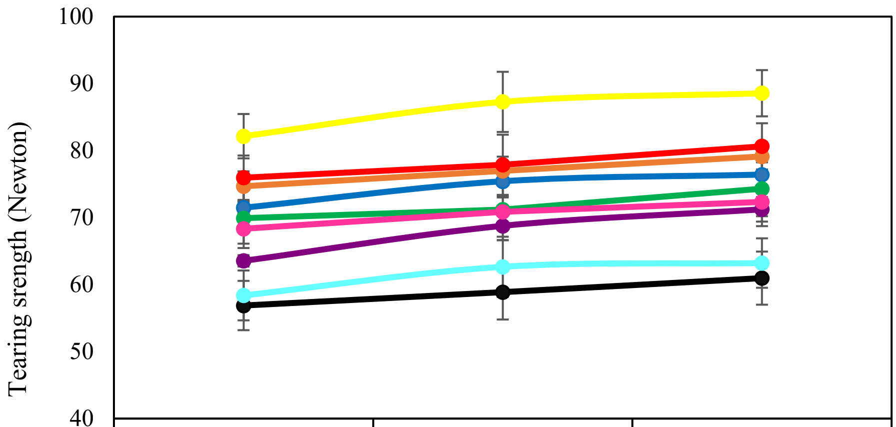
The tear strength of the fabrics was determined using a universal strength tester in accordance with the ASTM D5587-15 standard. This test method addresses the determination of the tearing strength of textile fabrics using the trapezoid method based on the constant rate-of-extension (CRE) principle. The trapezoid tear produces tension along a reasonably defined course such that the tear propagates across the width of the specimen. It is useful for estimating the relative tear depending on the nature of the specimen.

RESULT AND DISCUSSION

Tear strength at the greige state

The fabric's tear strength was tested in both the warp and weft directions. The tear strength was stated to be higher in the warp direction than in the weft direction. Satin fabric structures had the highest tear strength, twill had the second highest and plain had the lowest. The twist multiplier (TM) influences tear strength. At 3.8 TM, the tear strength was the lowest and as the TM value increased, the tear strength increased as well.

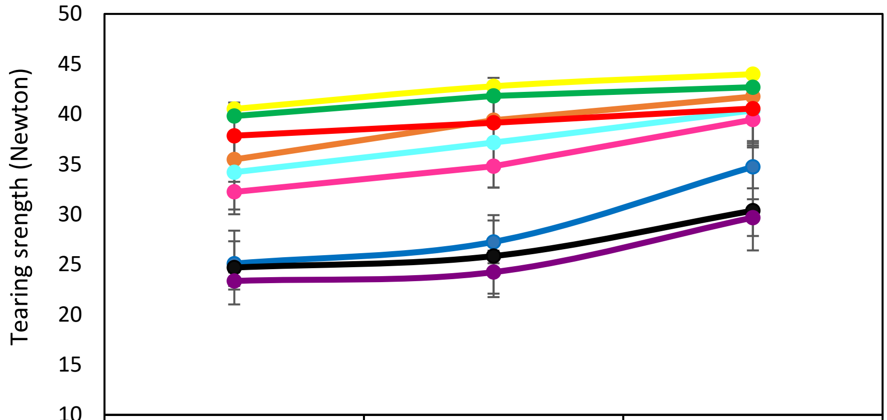
Figure 4 illustrates the tearing strength in the warp direction in a greige state. The tearing strength of a 100x60 plain fabric with a twist multiplier of 3.8 was initially measured at 71.47 N. As the twist multiplier value increased, the tearing strength also increased, reaching its highest value of 76.42 N at a twist multiplier of 4.2. The initial tearing strength of a 90x55 plain cloth with a twist multiplier of 3.8 was measured to be 56.87 N. As the twist multiplier value increased, the tearing strength also increased, reaching its highest value of 60.96 N at a twist multiplier of 4.2. The plain fabric with 95x50 yarn density also experienced an increasing pattern, with its tearing strength increasing from an initial value of 63.54 N at 3.8 TM to 71.23 N at 4.2 TM. The initial tearing strength of a 100x60 twill cloth with a twist multiplier of 3.8 was measured to be 74.67 N. As the twist multiplier value increased, the tearing strength also increased, reaching 79.12 N for a twist multiplier value of 4.2. Both the 95x50 twill and 90x55 twill fabrics exhibited an identical pattern in tearing strength. The tearing strength of 100x60 satin, 95x50 satin, and 90x55 satin fabrics exhibited a similar pattern of increase to that observed in plain and twill fabrics.



	TM 3.8	TM 4.0	TM 4.2
100X60 Plain	71,47	75,42	76,42
100X60 Twill	74,67	76,96	79,12
100X60 Satin	82,15	87,27	88,56
90X55 Plain	56,87	58,87	60,96
90X55 Twill	58,38	62,65	63,21
90X55 Satin	69,91	71,21	74,31
95X50 Plain	63,54	68,77	71,23
95X50 Twill	68,33	70,87	72,34
95X50 Satin	75,95	77,88	80,63

Figure 4. Tear strength at greige state in warp direction

Figure 5 shows the variation in tearing strength for different fabrics measured in the weft direction. For 100x60 plain weave fabric with a twist multiplier (TM) of 3.8, the initial tearing strength was recorded at 25.09 N, which increased with increasing TM values, reaching a maximum of 34.74 N at a TM of 4.2. A similar pattern was observed for 90x55 plain weave fabric, starting at 24.7 N and peaking at 30.37 N with the same range of TM. The 95x50 plain weave exhibited an initial tearing strength of 23.36 N, which increased to 29.68 N at a TM of 4.2. In the case of twill weaves, the 100x60 fabric showed an initial tear strength value of 35.48 N and demonstrated a growth in strength up to 41.75 N as the TM increased to 4.2. The 90x55 twill fabric's initial strength of 34.21 N similarly increased, reaching 40.37 N at a TM of 4.2. The 95x50 twill weave showed an initial strength of 32.24 N and reached a high of 39.45 N with an increased TM. For satin weaves, the initial tearing strengths of both 100x60 and 90x55 were around 40 N, with the strength rising with the TM to approximately 43 N for both types of fabric at a TM of 4.2. The 95x50 satin weave fabric had an initial strength value of 37.85 N and increased to roughly 40.56 N with a TM of 4.2. The data indicates that the tearing strength typically increased with higher TM values across all fabric types.



	TM 3.8	TM 4.0	TM 4.2
100X60 Plain	25,09	27,26	34,74
100X60 Twill	35,48	39,39	41,75
100X60 Satin	40,52	42,78	43,99
90X55 Plain	24,7	25,84	30,37
90X55 Twill	34,21	37,17	40,37
90X55 Satin	39,81	41,81	42,69
95X50 Plain	23,36	24,24	29,68
95X50 Twill	32,24	34,81	39,45
95X50 Satin	37,85	39,13	40,56

Figure 5. Tear strength at greige state in the weft direction

The tear strength of yarn depends on how strong a single yarn is, how smooth or rough it is (which affects how easily it slips and how much it stretches), how long it can stretch and how even it is. When the fabric is smooth, it can stretch more and carry more yarn load because they can be brought together more easily. This gives the yarns more freedom to move or slip, making them stronger to tear. Moreover, with a high twist factor, the fabric is less likely to tear than with a low twist factor. Also, it can be seen that there is a proportional relationship between thread density and tearing strength values. As the fabric's warp and weft densities increased, so tearing strength value increased. Several researchers have found that for a given set of yarns and texture, a fabric with less interlacement or binding points generally has a higher tearing strength [48]. In comparison to plain or twill fabric, satin fabric has a loose structure because of fewer binding points that allow thread clustering and resist tearing. Our study concluded the similar findings. However, it was further investigated that the fabrics manufactured of siro-spun have appropriate tear resistance. When comparing the tearing strengths of similar fabrics in the warp and weft directions, the pattern is found to be superior in the warp but poorer in the weft direction. Due to the increased strength and extensibility of warp yarn, warp-way tearing strength ranges between 57-88 N compared to 23-44 N for weft-way tearing strength. According to Krook and Fox, increasing the tensile strength of the yarn or making the fabric more slippery can help make the fabric more resistant to tearing. This is because the yarns will move more freely within the fabric structure, reducing friction effects [49]. Since the yarns have a low coefficient of friction, the yarns can move freely around the fabric, resulting in less slippage. Taylor acknowledged that the tearing strength of a cloth is dependent mainly on the spacing and strength of the threads being torn [50].

Stress-elongation behaviour of the fabrics

Stress-elongation in the warp and weft directions are discussed for three different fabric structures: plain, twill and satin, all were constructed with 4.0 TM yarns at 100 warp/inch and 60 weft/inch densities. Figure 6 indicates that stress is proportional to elongation up to a certain limit, after which stress does not increase considerably with the increase in elongation.

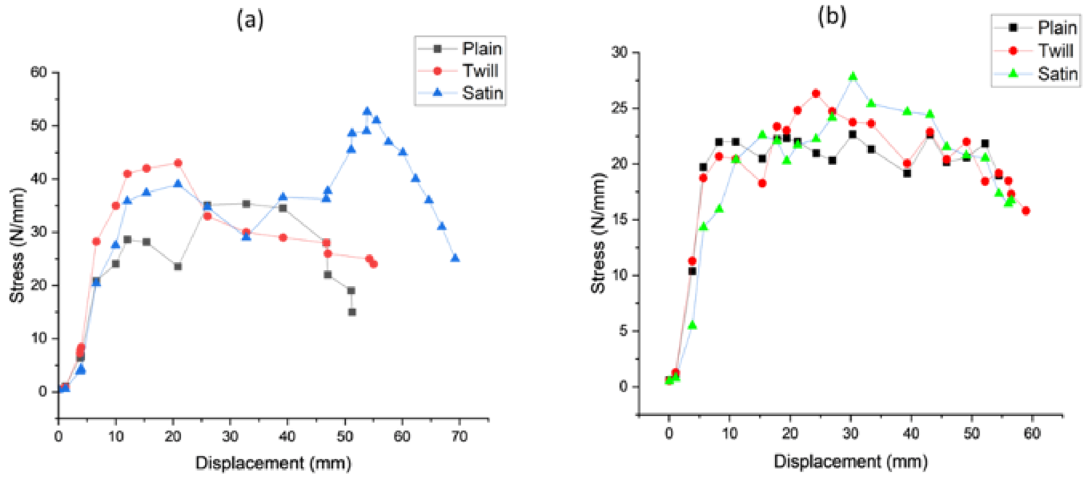


Figure 6. Stress-elongation curve for three woven structures. (a) Stress-elongation in the warp direction (b) Stress-elongation in the weft direction

Satin has the highest elongation and stress value in both the warp and weft directions, while plain fabric has the lowest. When tested in the warp direction, the plain-woven fabric can withstand up to 35 N/mm stress and 51 mm elongation, while it can withstand up to 23 N/mm stress and 55mm elongation when tested in the weft direction. The twill-woven fabric can withstand 43 N/mm of stress and 57 mm of stretch in the warp direction while it can only withstand 27 N/mm of stress and 60 mm of stretch in the weft direction. The satin woven fabric can withstand a maximum stress of 55 N/mm and a maximum elongation of 70 mm when tested in the warp direction. In the weft direction, however, the fabric can only withstand a maximum stress of 29 N/mm and a maximum elongation of 59 mm.

When there are fewer binding points on the surface of a woven fabric, it is easier for the weft yarns to pull away from the warp threads. Because of these slips, more weft threads get into the cross-sectional area. This also makes the fabric much stronger and makes it harder to tear. So, the fabric has a much higher tearing strength and a much longer floating time (like a satin structure).

Tearing strength after de-sizing, scouring and bleaching

After the processes of de-sizing, scouring, and bleaching, there was a notable reduction in tearing strength at both the warp and weft ends. Figures 7 and 8 indicated that all the fabrics experienced a higher percentage of strength loss in the warp direction than in the weft direction. Specifically, the warp direction showed reductions ranging from 33% to 43% for plain weaves, 35% to 41% for twills, and 24% to 43% for satins. For the weft direction, the reductions were 22% to 33% for plain weaves, 22% to 36% for twills, and 21% to 39% for satins. The removal of sizing material from the warp yarn surface contributes to the decreased tearing strength. The most significant loss in tearing strength, up to 45%, was seen in satin fabric with a 4.0 TM value and a density of 100x60, while the lowest decrease was seen 25% in satin fabric with a 4.2 TM value and the same yarn density. After all, the strength and elasticity of cellulosic fibres are affected by de-sizing, scouring and bleaching, which further reduces the tearing strength.

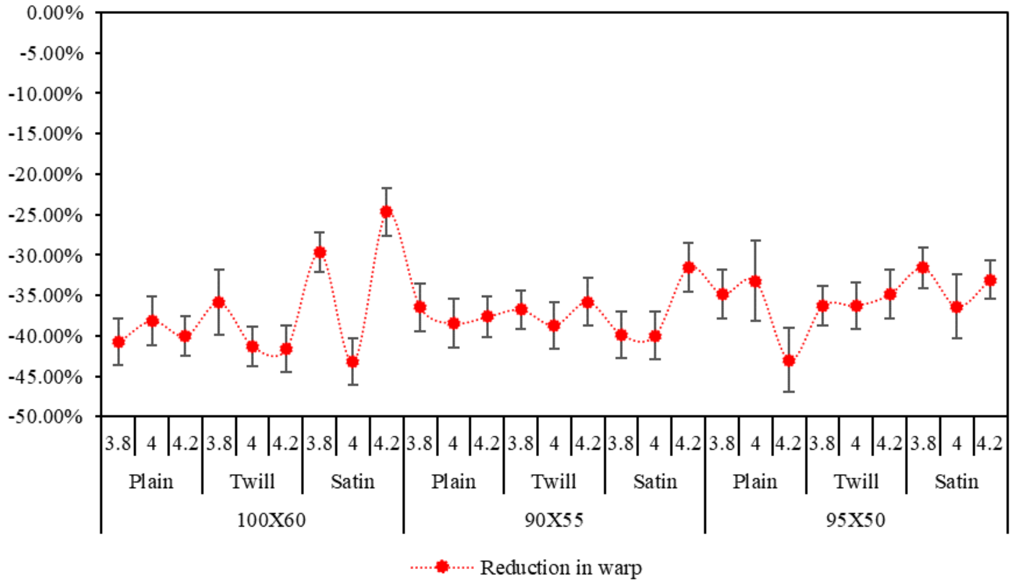


Figure 7. Reduction of tear strength in warp direction

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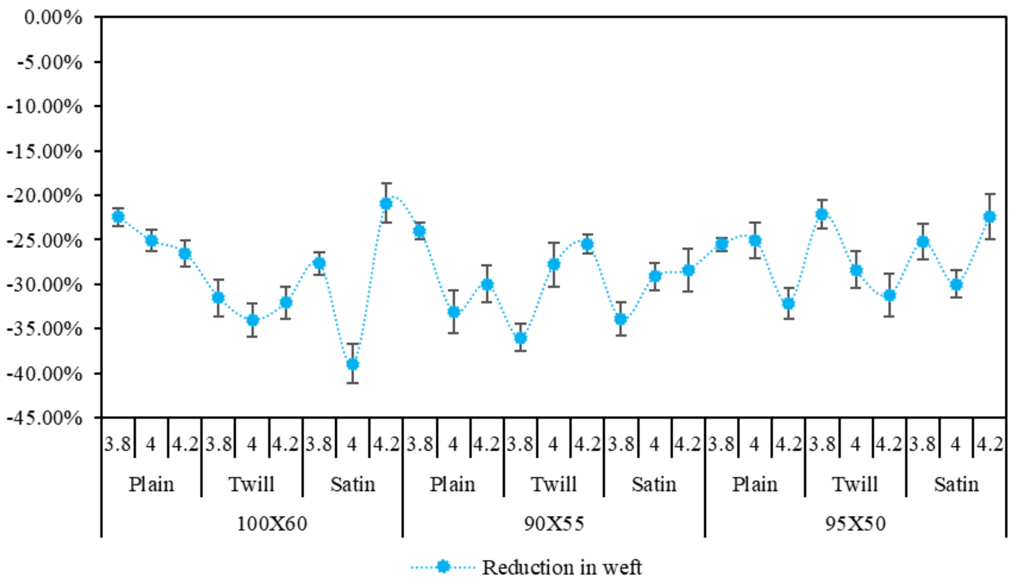

Figure 8. Reduction of tear strength in the weft direction

Regression analysis

Using multiple linear regression, a correlation between twist multiplier, warp density, weft density and tearing strength was determined. The independent variables were twist multiplier, warp density and weft density, while the dependent variable was the calculated average tearing strength in both warp and weft orientations. The tearing strength of plain, twill and satin fabric in both the warp and weft direction was predicted by individual regression model (1)-(6). All the influential variables which affected tearing strength value were included in the analysis. TM, warp density and weft density had their P- P-values less than 0.05 for all three fabric structures, indicating that TM, warp density and weft density significantly contribute to tearing strength (Table 6-11). R^2 values of all the regression models were close to 0.90, indicating that the regression models can predict approximately 90% of the tearing strength value of plain, twill and satin fabric. The tearing strength equations for plain twill and satin fabrics were derived from the regression analysis and are presented below:

$$S= 13.94 P+ 1.63 Q-0.16 R-135.13 \quad (1)$$

$$S= 11.075 P+ 1.64 Q-0.179 R-120.62 \quad (2)$$

$$S= 12.908 P+ 1.368 Q+0.099 R-108.47 \quad (3)$$

$$S= 18.033 P+ 0.0566 Q+0.299 R-66.69 \quad (4)$$

$$S= 16.366 P- 0.00844 Q+0.342 R-46.24 \quad (5)$$

$$S= 7.55 P- 0.0842 Q+0.367 R-1.374 \quad (6)$$

S= Tearing strength, P=Twist multiplier, Q=Warp density, R=Weft density

(1) Tearing strength at warp way for plain weave

(2) Tearing strength at warp way for twill weave

(3) Tearing strength at warp way for satin weave

(4) Tearing strength at weft way for plain weave

(5) Tearing strength at weft way for twill weave

(6) Tearing strength at weft way for satin weave

Table 6. Regression analysis for tearing strength of plain weave in the warp direction

Regression Statistics					
R Square	0.9850				
Adjusted R Square	0.9760				
Standard Error	1.1194				
Observations	9				
ANOVA					
	df	SS	MS	F	Significance F
Regression	3	411.508	137.169	109.471	0.00006
Residual	5	6.265	1.253		
Total	8	417.773			
	Standard Error	P-value			
TM	2.2849	0.0017			
Warp density	0.1055	0.0000			
Weft density	0.0487	0.0367			

Table 7. Regression analysis for tearing strength of twill weave in the warp direction

Regression Statistics					
R Square	0.9933				
Adjusted R Square	0.9893				
Standard Error	0.7288				
Observations	9				
ANOVA					
	df	SS	MS	F	Significance F
Regression	3	393.6034	131.2011	246.9854	0.000007
Residual	5	2.6560	0.5312		
Total	8	396.2594			
	Standard Error	P-value			
TM	1.4877	0.00069			
Warp density	0.0687	0.000002			
Weft density	0.0427	0.04731			

Table 8. Regression analysis for tearing strength of satin weave in the warp direction

Regression Statistics	
R Square	0.9877
Adjusted R Square	0.9803
Standard Error	0.9254
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	3	342.8604	114.2868	133.4466	0.00003
Residual	5	4.2821	0.8564		
Total	8	347.1426			

	Standard Error	P-value
TM	1.8890	0.0010
Warp density	0.0873	0.00002
Weft density	0.0543	0.0046

Table 9. Regression analysis for tearing strength of plain weave in the weft direction

Regression Statistics	
R Square	0.8658
Adjusted R Square	0.7853
Standard Error	1.7111
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	3	94.4489	31.4830	10.7532	0.0128
Residual	5	14.6389	2.9278		
Total	8	109.0878			

	Standard Error	P-value
TM	3.4927	0.0036
Warp density	0.1613	0.0074
Weft density	0.0461	0.0012

Table 10. Regression analysis for tearing strength of twill weave in the weft direction

Regression Statistics	
R Square	0.9824
Adjusted R Square	0.9718
Standard Error	0.5399
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	3	81.3654	27.1218	93.0613	0.0001
Residual	5	1.4572	0.2914		
Total	8	82.8226			

	Standard Error	P-value
TM	1.1020	0.00003
Warp density	0.0509	0.0087
Weft density	0.0168	0.0011

Table 11. Regression analysis for tearing strength of satin weave in the weft direction

Regression Statistics	
R Square	0.9820
Adjusted R Square	0.9712
Standard Error	0.3334
Observations	9

ANOVA

	df	SS	MS	F	Significance F
Regression	3	30.3224	10.1075	90.9489	0.0001
Residual	5	0.5557	0.1111		
Total	8	30.8780			

	Standard Error	P-value
TM	0.6805	0.0001
Warp density	0.0314	0.0438
Weft density	0.0665	0.0001

Comparison between siro-spun and ring-spun fabric

Three fabric samples were created by blending fibres in a 50/50 ratio of cotton and lyocell using ring-spun technology. These samples had specifications of 25/1 Tex, 100x60 yarn density and different TM values of 3.8, 4.0 and 4.2. They were then compared to three other fabric samples produced using 50/50 cotton-lyocell siro-spun yarn to investigate the variations in tearing strength between siro-spun and ring-spun fabrics.

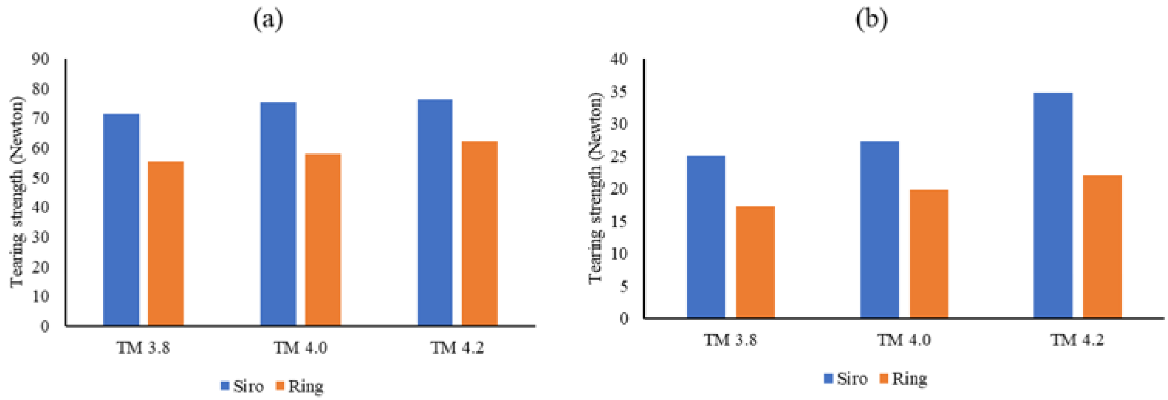

Figure 9. Comparison of tearing strength between ring spun and siro spun fabric (a) comparison of tearing strength in warp direction (b) comparison of tearing strength in the weft direction

Figure 9 shows that 50/50 cotton-lyocell siro-spun fabric has an overall 23-30% higher tearing strength in the warp direction and a 38-57% higher tearing strength in the weft direction compared to 50/50 cotton-lyocell ring-spun fabric. Unevenness in the fibre causes strength irregularities. The hairs that surround the yarn axis are spun onto the yarn surface, which increases strength by improving yarn density and reducing unevenness. Siro yarns have a higher packing density than ring yarns, which is one of the elements that contribute to their improved strength. Siro yarn has a higher fibre migration rate, a higher spinning coefficient, a higher straight fibre ratio, less yarn breakage and less hairiness than other yarns.

CONCLUSION

The strength of a 50/50 cotton-lyocell siro spun woven fabric is greater than that of a 50/50 cotton-lyocell ring-spun woven fabric. The tearing strength of a 50/50 cotton-lyocell woven fabric is affected by the twist multiplier and fabric structure. Satin weaves have higher tearing strength than twill and plain weaves because they have a lower interlacement point within the specific area. The twist multiplier enhanced the tearing strength proportionately. Overall, the warp direction demonstrated stronger tearing strength than the weft direction.

Author Contributions

Conceptualization – Afroz F, Akter S, Islam MM, methodology –Afroz F, Akter S, Ahmed DM; formal analysis – Islam MM, Afroz F; investigation – Islam MM, Afroz F; resources – Afroz F, Ahmed DM; writing - Islam MM, Afroz F; writing-review and editing – Afroz F, Islam MM, Akter S, Ahmed DM; visualization – Islam MM; supervision – Afroz F. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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