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Enhancing the Mechanical Properties of Warp-Knitted Elastic Tapes

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ABSRACT

Elastic tape is considered one of the most important clothing accessories because it affects both the functional and aesthetic performance of the apparel. These tapes are manufactured on warp knitting machines with the required width. The problem that many users faced was that the elastic tapes used in garment manufacturing are greatly affected by repeated use due to the stress they are subjected to during use and during washing. Many factors and different constructions influence the mechanical and aesthetic performance of elastic tapes. In this study, various variables were divided into three groups to determine which would achieve the best conditions for tape production. The samples were tested with selected properties such as width shrinkage after washing, tensile strength and elongation percentage, length shrinkage between both sides after washing the elastic tapes, and tension decay (%, %). The weight and the thickness of the produced elastic tapes were also identified. The results of the mechanical properties were statistically analyzed, indicating that both the tape width and the percentage of rubber threads significantly affect the tested properties. Furthermore, most of the functional properties of elastic tapes improve within a range of 1.5–3.1 cm in width and a rubber thread percentage of 83.1 %. and a rubber thread percentage of 83.1% and which subsequently affects the performance and durability of garments during repeated use and washing cycles.

Keywords: Warp knitted, Elastic tape, Rubber threads, Garment washing, Shrinkage

1. Introduction

Clothes, especially those containing elastic tape accessories, are exposed to a range of stresses during the washing and drying process, starting from slight twisting until deformation, leading to discomfort during wear (Cesa et al., 2020; Scheid et al., 2016). Keeping the aesthetic aspects and functional properties of the elastic band is the research goal. People choose clothes to wear depending on their requirements and preferences (Abdel-Megied & Abd El-Aziz, 2018; El-Aziz et al., 2024; Salman & El-Aziz, 2024; Shawky et al., 2024; Seddik et al., 2025), as clothes are worn every day for physical comfort (Abo El Naga & Abd El-Aziz, 2023; El-Moursy et al., 2023; Salman & Abd El-Aziz, 2025).

Elastic Band alludes to a narrow stretchy fabric with elongation properties made of a flexible substance that can revert to its original shape after being stretched or which is woven together with other fibers to create these types of bands (Algamal, 2015; Gent, 2005). In clothing, elastic bands are frequently used as accessories suitable for underwear, pants, baby clothes, sweaters, sportswear, aerobic clothing, T-shirts, hats, masks, and other clothing products (James & Guth, 1943). The most important factors to consider when choosing narrow fabric elastic tapes for garments are elongation, modulus, durability, texture, and aesthetics (Setiyana et al., 2018; Setiyana, Ismail, Jamari, et al., 2021).

Elastic bands can be produced by many techniques, such as knitting, braiding, and weaving (Eom & Lee, 2021). Braided elastic, with parallel edges, provides grip but tends to thin with stretching and roll more easily than knitted or woven elastics. It's best used in casings, necklines, sleeves, and areas where rolling isn't a major issue. Woven elastic, also known as non-roll elastic, is the firmest of the three basic elastic types, suitable for sewing on applications and heavier-weight fabrics. Finally, a warp or weft knitted elastic band is softer than braided or woven ones and retains its width when stretched (Zhang et al., 2020). Owing to their yarn-looping structure, knitting construction usually exhibits unique performance properties (Abdel-Megied et al., 2020; El-Aziz et al., 2023; Elsayed et al., 2025), It's suitable for light to mid-weight fabrics but lacks grip for heavier ones (Darwish et al., 2023; Morgham et al., 2023). It is also a suitable option for sew-on applications because it remains effective even after being punctured by needles. Compared to woven elastic, it rolls more, but not as much as braided elastic (Eom & Lee, 2021).

Warp-knitted elastic tapes are also called crochet elastic tapes (Yip, 2016). The weft inlay is what connects the chaining wales on crochet machines; the warp chains are not connected. The wefts present a set of stiff monofilament yarns to provide good transverse dimensional stability against bending or rolling of the tapes during their use, and warp yarns are divided into sets of elastic yarns inlaid therein to provide longitudinal stretch. Multiple sets of relatively inelastic yarns forming a knitted ground construction make up the warp-knit elastic fabric construction. Additionally, to successfully conceal the elastic yarns in the tape structure, the construction may include many covering yarns, such as textured yarns (Dorgham et al., 2019; Spencer2001 ,).
The stitch formation to produce one course of loops on a crochet machine starts with weft inlaying, followed by moving the needle out of its track to clear its old warp overlap. Then, the warp guide rises between the needles and automatically overlaps from the left, lowering itself again on the right side of its needle. Finally, warp knock-over and underlap (Spencer2001 ,).

Elastic yarns may have a natural or synthetic resource (R. Lozada et al., 2023; Surajarusarn, 2020). Rubber is one of the most important natural resources (Distler, 2001). Numerous varieties of trees can produce natural rubber (Perumal et al., 2013). With its high tensile strength, high tear strength, high elasticity, good resistance to crack growth, and low heat buildup, natural rubber is regarded as a biomaterial with high-performance qualities (Sethulekshmi et al., 2022). Natural rubber, despite its excellent physical properties, has limitations like low heat, abrasion, and flame resistance, and poor ageing properties, necessitating modification through molecular structure changes and new atom introduction. Gas and petroleum are used to make synthetic rubber. It is produced by polymerization of 1,3-butadiene derivatives or by copolymerization of 1,3-butadiene along with an unsaturated monomer (Bin Samsuri, 2010). Because of its excellent heat resistance and heat-ageing characteristics, synthetic rubber also performs well at high temperatures (Pocius, 2012).

The cross-section of the rubber or gum yarn affects its mechanical properties (Dong et al., 2021). It could be manufactured as a circular or square (Karaca et al., 2015). Rubber yarns such as latex and spandex thread may be used individually or as cores for inelastic yarns such as cotton and polyester yarns (Markova, 2019). Ghada Al-Gamal has explained the effects of different types of elastics, attachment methods, and stretching degree on fabrics. Using 2cm width raw elastic proved the highest elongation results and best appearance. However, using 2cm width knitted elastic proved superior abrasion resistance due to its structure of single jersey.

The outcome of cleaning laundry is impacted by four interconnected elements, as mentioned in the Sinner Circle (Setiyana, Ismail, & Jamari, 2021). The chemical activity of an acid or alkaline cleanser arrangement increases or decreases with the concentration of unadulterated items within the arrangement. Besides, mechanical action generates friction and pressure. Also, elevated temperatures support the reaction process and weaken the binding forces of the soil to the fabric. Additionally, cleaning time works on the textiles to remove stains (Abeliotis et al., 2015). Indeed, elastic materials are more affected by the same previous four elements, which weaken their elasticity and then break down (Kirstein & Rodel, 2000).

In the case of the following care instructions, some elastic tapes joined with clothes may be turned wavy. Research that discusses enhancing mechanical properties showed that the tightness factor significantly impacts elastic band behavior, with polyester microfiber cross-section affecting major functional properties and elasticity characteristics, while yarn count and sample structure directly affect properties. In the mentioned research, the authors used two distinct polyester microfiber cross-sections—Circular and Trilobal—and a yarn count of 150/288 denier was utilized to weave six elastic band samples. There were three distinct stitch densities used. The band construction was created using an open pillar stitch chain (1-0/0-1) and a spandex yarn count 40 tex. Each sample was created using a crochet knitting machine (Seddik & Ali, 2022). Other researchers focused on determining the elastic properties of rubber bands, revealing that they do not follow Hooke's law and their initial lengths affect the stretch response for loading. The results showed that shorter bands stretched less than longer ones for similar loading, rejecting the hypothesis and suggesting further research on rubber band properties and molecular structure (Davuluri & Ravipati, 2022).

The expected parameters to maintain the elastic apparel and comfort properties are fiber types, yarn cross-section, stitch, elastic yarn ratio, and tape width. This research focuses on the effect of different tape widths and rubber thread percentages in the elastic tapes on their mechanical properties to find a solution to the elastic tapes' deformation by repeated use due to the stress they are subjected to during use and also during washing.

2. Experimental Work

2.1. Material

Two sets of yarns were used in the warp: polyester 150/1 denier (which means 9000 meters of polyester yarn weighs 150 grams), and rubber threads 40 (which means 40 rubber threads can be inserted in 1 inch). One type of yarn is used as the weft insertion (polyester 150/1 denier) by two sets (front and back), as shown in Figure 1.

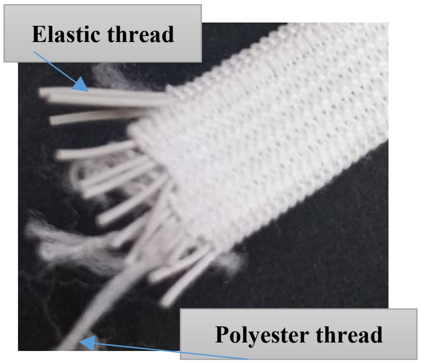


Figure 1. Image of the elastic and polyester threads inserted into samples

2.2 Method

2.2.1 Producing Elastic Tape Samples

Based on previous studies, warp knitted elastic tapes were specifically chosen due to their superior structural stability, enhanced elasticity control, and better durability compared to weft-knitted alternatives. Three groups of warp knitting tapes were produced, with the same structure (0/1/0/1) as shown in Figure (2) using a Muller crochet machine, manufactured in Switzerland, gauge 18, with two guide bars, and one needle bar, to study the effect of different variables. Samples are grouped into three categories as follows:

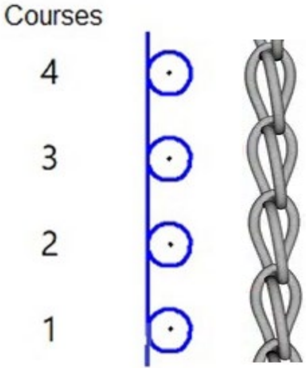


Figure 2. Illustration image of the structure of the samples: pillar stitch (closed chain) [39], [40]

Group (1): The effect of different widths, with the same rubber thread percentage (71%) but a varying number of rubber threads, on the tested properties.

This group consists of seven elastic tape samples with different numbers of rubber threads inserted in the warp direction (2, 6, 8, 10, 13, 16, 20), as shown in Figure 3. In all samples in this group, the warp yarns were arranged in a 1:1 ratio (one polyester yarn to one rubber thread), as illustrated in Table 1.

Table 1. The specification of samples in Group (1) (Effect of different widths with the same rubber thread percentages)

Sample	Rubber threads Percentage /warp (%)	NO. of Rubber threads	Sample width (cm)	Warp arrangement	Weight (g) +/- SD.	Thickness (mm) +/- SD.
E	71	2	0.2	**1**Polyester yarn: **1**Rubber thread	1.12 +/- 0.01	1.3 +/- 0.01
E0		6	0.9		4.48 +/- 0.08	1.36 +/- 0.02
E1		8	1.1		5.72 +/- 0.09	1.43 +/- 0.01
E2		10	1.5		7.28 +/- 0.03	1.38 +/- 0.01
E3		13	2		8.95 +/- 0.07	1.36 +/- 0.01
E4		16	2.4		11.17+/- 0.01	1.35 +/- 0.02
E5		20	3		15.90+/- 0.28	1.49 +/- 0.08

After producing and testing samples with different widths in group 1, only two widths (1.4 cm, and 3.1 cm) were chosen to test the effect of different rubber thread percentages on the mechanical and aesthetic properties of elastic tapes before and after use in the follow group 2. These two widths were chosen as they are the most needed in the clothing industry, especially for pants and bra applications.

Figure 3. Image of the Samples of group (1)

Group (2-A): Examining the effect of varying rubber thread percentages on a constant narrow tape width of 1.4 cm, as produced by the machine.

This group consists of three elastic tape samples with different rubber thread percentages (71%, 75.5%, and 83.1%) in the warp direction, all produced with the same width on the machine (1.4 cm) as shown in Figure 4. The difference in rubber thread content arises from varying warp arrangements, as illustrated in Table (2).

Table 2. The specification of samples in Group (2-A) (Effect of different rubber thread percentage in narrow tape width)

Sample	Rubber threads percentage/ warp meter (%)	NO. of Rubber threads	Sample width on the machine (cm)	Warp arrangement	Weight (g) +/- SD.	Thickness (mm) +/- SD.
E1	71	8	(Narrow width) 1.4 cm	**1**Poyester yarn: **1**Rubber threads	5.7 +/- 0.1	1.43 +/- 0.01
E6	75.5	10		**1**Poyester yarn: **1**Rubber thread, with adding **1** Rubber thread per each side	6.2 +/- 0.1	1.39 +/- 0.01
E7	83.1	16		**1**Poyester yarn:**2**Rubber threads	7.5 +/- 0.1	1.4 +/- 0.04

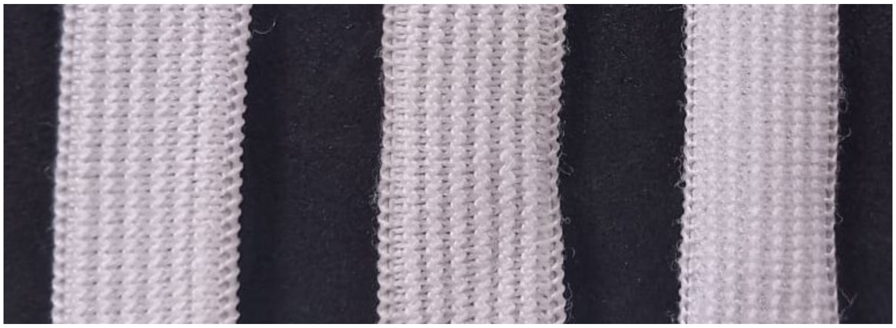


Figure 4. Image of the Samples of group (2-A)

<u>Group (2-B)</u> (the effect of the rubber thread percentage per the same wider tape width on the machine, 3.1 cm);

This group consists of three elastic tape samples of different rubber thread percentages (71%, 78.7%, and 83.1%) in the warp direction, all produced with the same tape width on the machine (3.1 cm) as shown in Figure (4). The difference in rubber thread content arises from varying warp arrangements, as illustrated in Table (3).

Table 3. The specification of samples in Group (2-B) (Effect of different rubber thread percentages in <u>wide tape</u> width)

Sample	Rubber threads Percentage (%)	NO. of Rubber threads	Sample width (cm)	Warp arrangement	Weight (g) +/- STDV.	Thickness (mm) +/- STDV.
E5	71	20	(Wider width) 3.1 cm	**1** polyester yarn**:** **1** Rubber thread	16.1 +/- 0.3	1.49 +/- 0.08
E8	78.7	30		**1** polyester yarn**:** **2** Rubber threads**:** **1** polyester yarn**:** **1** Rubber thread	17.2 +/- 1.1	1.43 +/- 0.03
E9	83.1	40		**1** polyester yarn**:** **1** Rubber thread	21.5 +/- 0.5	1.43 +/- 0.02

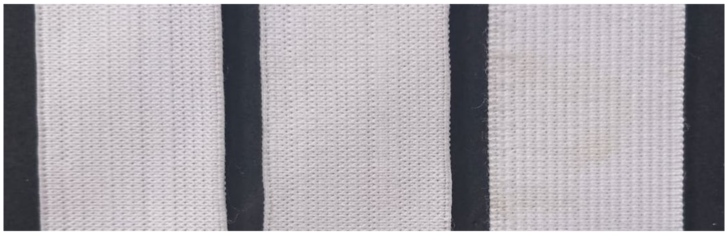


Figure 5. Image of the Samples of group (2-B)

2.2.2 Characterization methods of elastic tapes

All the samples were handled according to the conditions specified in the standard method (ISO 139) for textile testing for 24 hours, which include a temperature of 20 ± 2 ºC and a relative humidity of 65 ± 4%. The samples were washed according to the standard method (AATCC standard 2020 reference liquid detergent without optical brightener (WOB) and an accelerated laundering machine with a temperature of 90 °C) and flat dried at room temperature according to (ISO 6330). The longitudinal weight regarding (ASTM D 3776), and the thickness of the samples regarding (ASTM D1777) were identified. Also, six different properties were measured after relaxation for 24 hours. Five parallel measurements were taken for each sample, and the mean was used. These properties were:

The elastic tapes' width shrinkage was determined by measuring the tapes' width before and after washing (using a standard sample length of 10 cm at 90 °C). The shrinkage in width for each sample was then calculated using formula (1) as follows:

$$Width\ shrinkage\ \% = \frac{(W_2 - W_1)}{W_1}\ x\ 100 - - - - - - - (1)$$

Where; **W**$_1$ is the width before washing, and **W**$_2$ is the width after washing.

The tensile strength and the elongation percentage were determined using an Instron testing machine (Instron, USA) in accordance with (ASTM D 3759/D3759M-05).

Length shrinkage after washing between the two sides was measured by cutting a standard length of 10 cm from each sample and then washing at 90 °C according to the mentioned standard. After washing, both sides of each sample were measured, and the average was calculated. The length shrinkage percentage after washing was then calculated by the following formula (2):

$$Length\ shrinkage\ \% = \frac{(L_2 - L_1)}{L_1}\ x\ 100 - - - - - - - (2)$$

Where; **L**$_1$ is the length of side 1 (left side in m/c direction), **L**$_2$ is the length of side 2 (right side in m/c direction)

Elasticity (%) :Also, the extensometer test was conducted using the specified force of 15 N and a pre-tension force of 0.5 N to determine the elasticity (%) before and after washing following the standard method (BS 4952(2.2)). Formula (3) was used to calculate the percentage variation in elasticity after washing.

$$Difference\ in\ elastisity\ \% = \frac{(E_b - E_a)}{E_a}\ x\ 100 - - - - - - - (3)$$

Where; **E**$_b$ is the elasticity before washing, and **E**$_a$ is the elasticity after washing.

Tension decay (%): An extensometer with a constant rate of extension, capable of cycling 3 cycles with test lengths of 200 mm, was used to determine the tension decay (%) according to the standard method (BS 4952(2.3)).

2.2.3 Statistical Analysis methods of the elastic tapes

Correlation factors (R^2) were calculated to determine the suitability of a linear relationship between factors (the number of rubber threads with the same rubber thread percentage in different widths and the effect of the rubber thread percentage per the same tape width in cases of narrow and wide widths) and the measured properties in each group. Furthermore, the results were statistically ranked by radar charts in each group to identify the best samples based on their performance. Finally, a one-way ANOVA test with a P-value at a 95% confidence level was performed to study the significant effect of the selected factors on the tested properties, within the same framework.

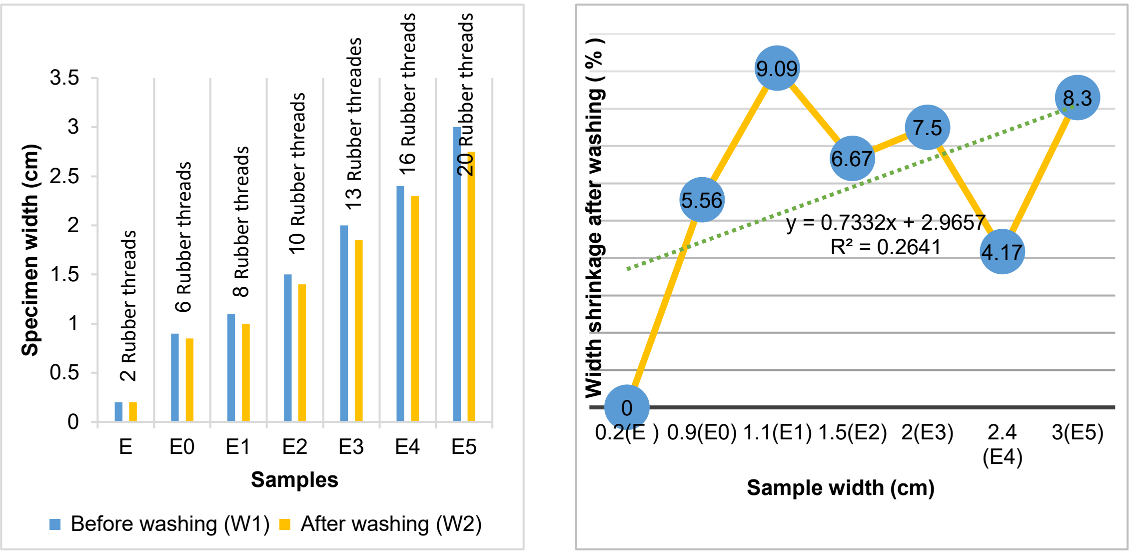
3. Result and discussion

3.1 Analysis of group 1

Group (1) studied the effect of different widths of the elastic tapes with the same rubber thread percentage on various characteristics. The results showed that varying the width of the elastic tape had a significant impact on the characteristics being studied: tensile strength at maximum load, the elongation at maximum load, the elasticity percentage, and the tension decay. However, it had an insignificant effect on the width shrinkage percentage and the shrinkage length. Therefore, it is important to consider both length and width when determining the best dimensions to prevent tape distortion and maintain dimensional stability after washing.

3.1.1 The relation between the sample width and the width shrinkage percentage after the washing process at 90 °C.

The sample width refers to the initial measurement of the fabric before washing, while the width shrinkage percentage indicates the reduction in fabric width after being washed, as the temperature has a high effect on the mechanical properties because it changes the molecular arrangement of rubber, and this is compatible with Kaiser study (Wang et al., 2013). This relationship is important for understanding how different elastic tape widths will react to washing and how to make adjustments for optimal designs accordingly.



A **B**

Figure 6. A Group 1 sample's width before and after washing versus sample code, B Relation between group 1 sample's width and width shrinkage% after washing

From Figure (6-A), it is clear that width shrinkage occurs at all selected widths after washing, except for the sample with two rubber threads, which show no change. As illustrated in Figure (6-B), the shrinkage percentage increases with the sample width, but this increase is not linearly related to the width, as indicated by the R² value, suggesting that width is not the only factor affecting shrinkage.

3.1.2 The relation between the sample width and the tensile strength at maximum load

Figure (7) also demonstrates that the tensile strength at maximum load decreases as the sample width increases, indicating a strong negative correlation between these two variables. This suggests that the sample width plays a significant role in determining the tensile strength of the elastic tape. This agrees with mentioned that changing the dimensions of the sample affects the tensile strength and elongation (Zhao et al., 2009).

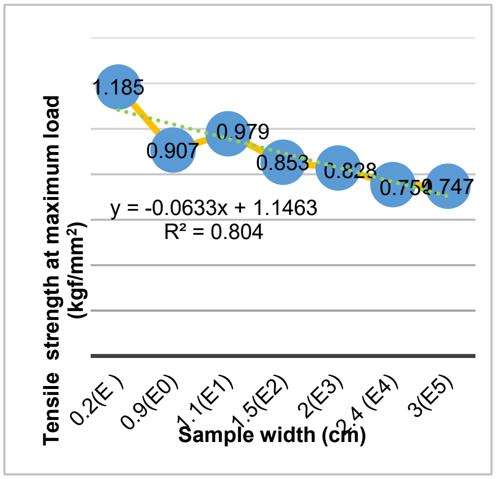


Figure 7. The relation between group 1 samples' width and tensile strength at maximum load

Samples with smaller widths exhibit higher tensile strength. this may be due to having fewer rubber threads in the warp direction. This could be attributed to the distribution of tension across the fabric, where narrower samples experience more uniform stress. Additionally, the presence of fewer rubber threads in narrower samples may contribute to their higher tensile strength after washing.

3.1.3 The relation between the sample width and the elongation at maximum load

Figure (8) exhibits lower elongation at maximum load of the narrower samples compared to the wider samples, indicating that sample width affects the fabric's ability to stretch before breaking. This suggests that the distribution of tension and rubber threads in the warp direction may influence not only the tensile strength but also the elongation properties of the fabric after washing.

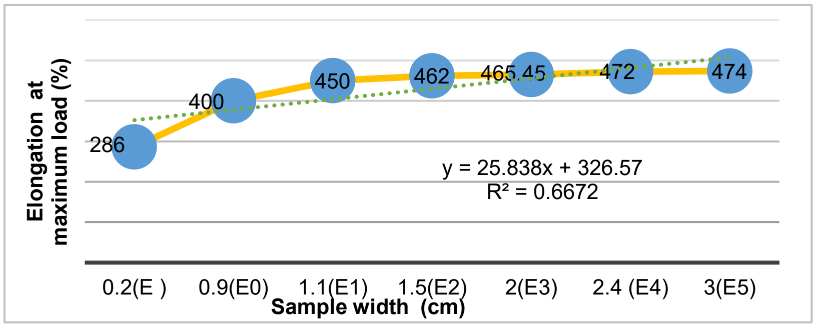
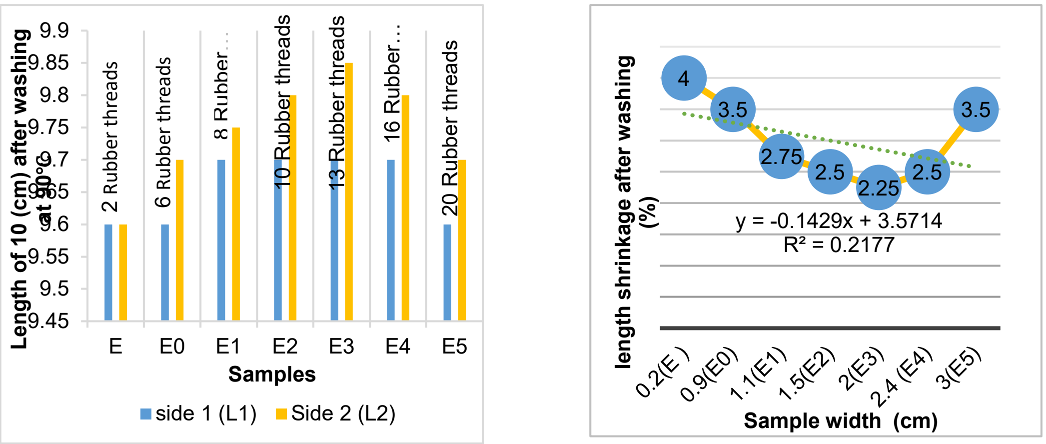


Figure 8. The relation between group 1 samples' width and elongation at maximum load

Also, Figure (8) clearly shows that the relationship between elongation at maximum load and elastic tape width is a moderate positive linear correlation. However, the increase is minimal for the sample with a width greater than 1.1 cm.

3.1.4 The relation between sample width and length shrinkage between the two sides of 10 cm after washing at 90 °C

From Figure (9-A), it is clear that there is a difference in the length of shrinkage between the two sides after washing, particularly for the sample with less width and two rubber threads. As shown in Figure (9-B), the length shrinkage percentage decreases with an increase in width up to 2 cm, after which it begins to increase.



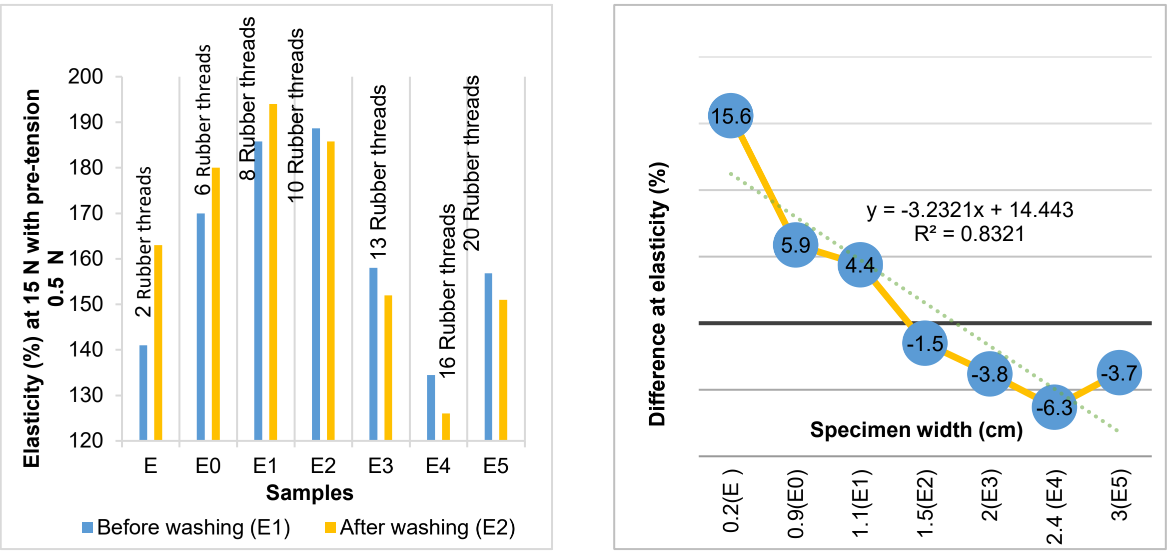
A B

Figure 9. A Group 1 samples' length at side 1 and side 2 of each sample after washing versus sample code, B The relation between group 1 sample's width and the mean of length shrinkage after washing

That means tape distortion will increase when the width exceeds 2 cm. Therefore, to ensure better functional performance, the optimal width for this property should not exceed 2 cm, indicating that sample width can also influence the fabric's dimensional stability after washing.

3.1.5 The relation between sample width and the percentage of elasticity at 15 N with pre-tension 0.5N

The elasticity of elastic tapes measures how much the tape can stretch and return to its original shape. This property is crucial for providing comfortable and secure support during physical activities. As shown in Figure (10-A), it is clear that the elasticity in the sample length after washing is higher than before for widths up to 1.1 cm, after which it starts to decrease. However, the difference begins to increase again when the width exceeds 2 cm.



A

B

Figure 10. A The percentage of elasticity at 15 N with Pre-tension 0.5N before and after washing and group 1 samples' width, B The relation between group 1 sample's width and the difference in elasticity percentage after washing

Figure (10-B) indicates that the optimal width in this case is 2 cm, as the tape maintains its dimensional stability and exhibits greater resistance to changes or distortion after washing. Therefore, this width is preferred for functional and aesthetic performance.

3.1.6 The relationship between Sample width and the percentage of tension decay

When interpreting the tension decay as a percentage loss in the tape elasticity, Figure (11) shows that the tension decay has an inverse linear relationship with tape width up to 1.1cm. Beyond this point, the relationship stabilizes, remaining nearly constant for wider tapes.

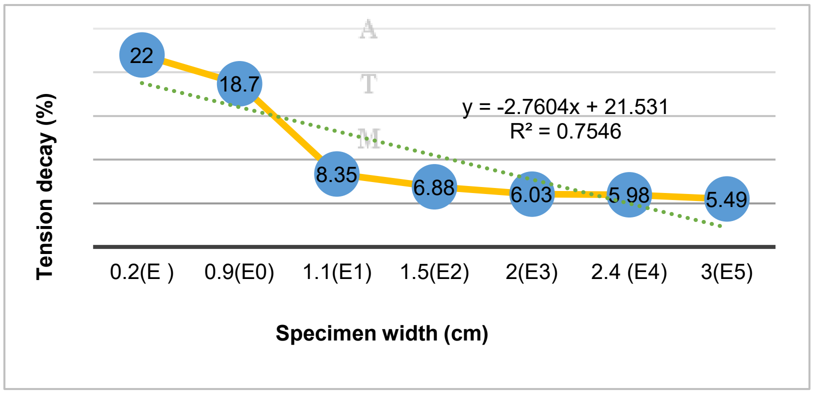


Figure 11. The relation between group 1 samples' width and the tension decay

This indicates that this property improves as tape width increases up to 1.5 cm, and after which it remains nearly constant as width continues to increase, given that the rubber thread percentage in the warp remains constant at 71%.

Thus, these results can be derived from the analysis of Group (1):

- The width of the elastic tape has significantly affected the tested properties
- Most properties improve as the width increases, up to 2 cm.
- The optimal width, when the rubber thread percentage in the warp remains constant at 71%, is 1.1 cm.

3.1.7 Ranking of Elastic Tape Samples in Group 1 Using Radar Charts

Radar charts for Group 1 of the elastic tape samples, shown in Figure (12), reveal that sample E2, with 10 rubber thread yarns per width, ranked first with the largest radar chart area. It exhibited superior performance across all tested properties compared to samples with a larger number of rubber thread yarns, such as E5 and others, as demonstrated in Figure (12) and Table (4).

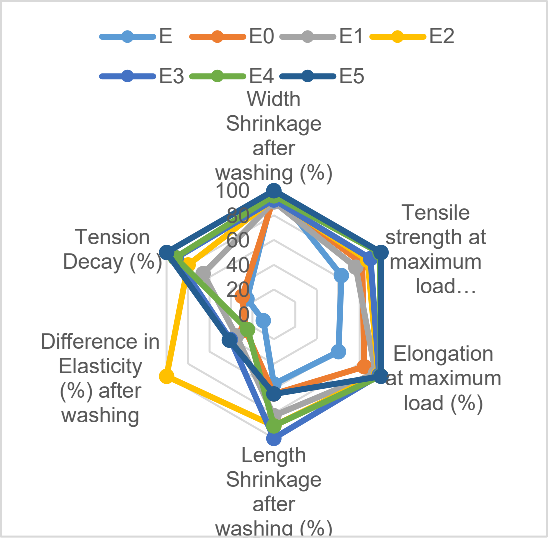


Figure 12. radar charts of group 1 samples with the same rubber thread percentages, different widths)

Table 4. Radar chart areas of group 1 samples

Rank	Sample code	Number of rubber threads	Radar chart area
1	E2	10	21460
2	E5	20	18599
3	E3	13	18566
4	E4	16	17862
5	E1	8	14217
6	E0	6	10910
7	E	2	7223

3.2 Analysis of Group 2

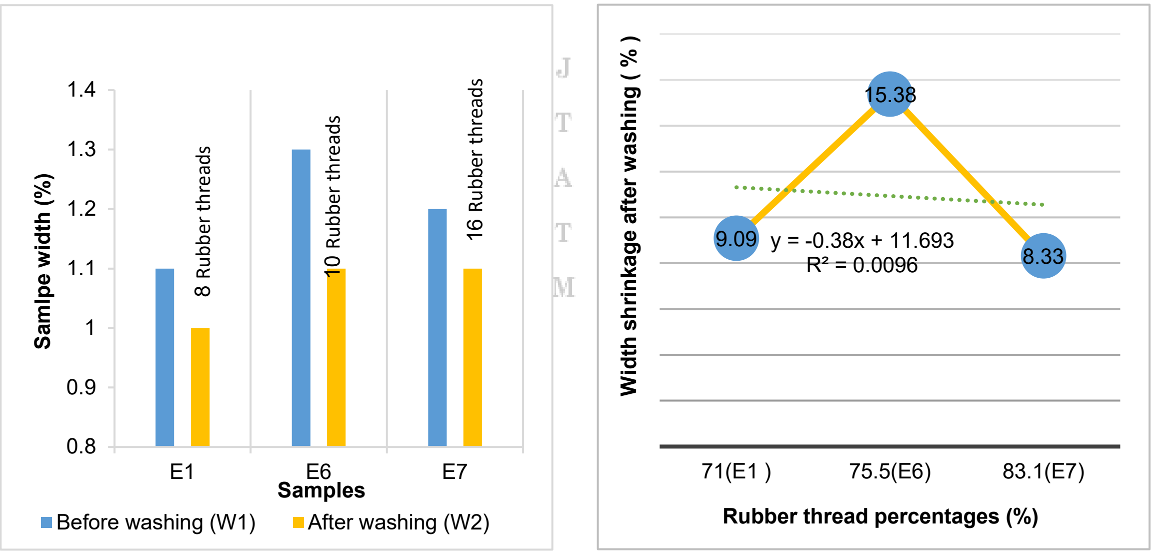
Group 2 studied the effect of different rubber thread percentages at the same width, using narrow (1.4 cm) and wide (3.1 cm) tape widths. The narrow-width group included rubber thread percentages of 71%, 75.5%, and 83.1%, while the wide-width group had rubber thread percentages of 71%, 78.3%, and 83.1%. The results showed a clear difference in the mechanical properties between the two groups. Further analysis revealed that the narrow-width group exhibited greater elasticity and shrinkage after washing compared to the wide-width group.

3.2.1 Group (2-A) (Effect of different Rubber thread percentages in the same width used narrow-width of 1.4 cm on the machine)

The narrow-width group with rubber thread percentages of 71%, 75.5%, and 83.1% exhibited varying mechanical properties, indicating that the rubber thread percentage significantly affects the elasticity and tension decay, but has little impact on width shrinkage after washing, tensile strength at maximum load, elongation at maximum load, and length shrinkage after washing.

3.2.1.1 The relation between the rubber thread percentages and the width shrinkage percentage after the washing process

The findings suggest that the percentage of rubber thread in the narrow tape composition plays a crucial role in determining its mechanical properties. Specifically, the effect of decreasing the width of the elastic tape varies depending on the rubber thread content.



A B

Figure 13. A Group 2-A samples' width with different rubber thread percentages before and after washing versus sample code, B Relation between group 2-A samples' rubber thread percentages and width shrinkage% after washing

As shown in Figure (13-A), there is a clear difference in the widths of the different rubber thread percentages before and after washing. Figure (13-B) demonstrates that the expected linear relationship is not applicable between the rubber thread percentages and width shrinkage. The least width shrinkage occurs at a rubber thread percentage of 83.1% in the case of narrow tape, which is preferable.

3.2.1.2 The relation between the rubber thread percentages and the tensile strength at maximum load

This data is crucial for determining the optimal rubber thread percentage to achieve the desired tensile strength in elastic tape production. Figure (14) clearly shows that tensile strength decreases as the rubber thread percentage increases from 71% to 75.5%, then begins to increase up to 83%.

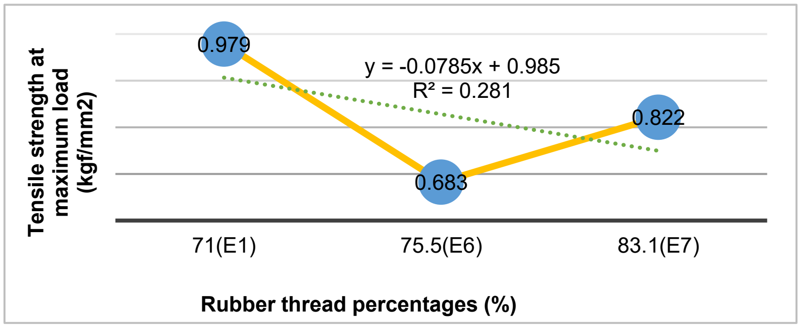


Figure 14. The relation between group 2-A samples' percentage of rubber thread and tensile strength at maximum load

This can be explained by the effect of rubber threads on weakening the fabric structure. It is also important to note that the relationship shown is not linear. The optimal condition for this case, in terms of rubber thread percentage, was 71%.

3.2.1.3 The relation between the rubber thread percentages and the elongation at maximum load

The results indicate that elongation at maximum load also follows a similar trend, initially decreasing and then increasing with the percentage of rubber threads.

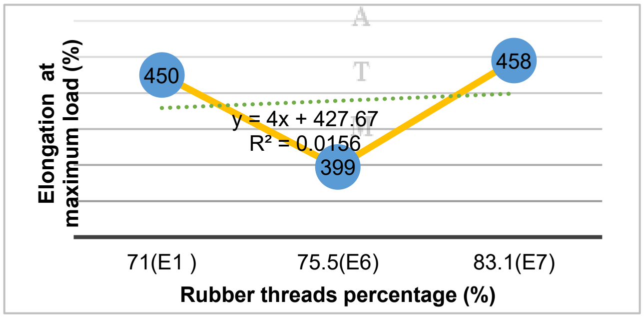


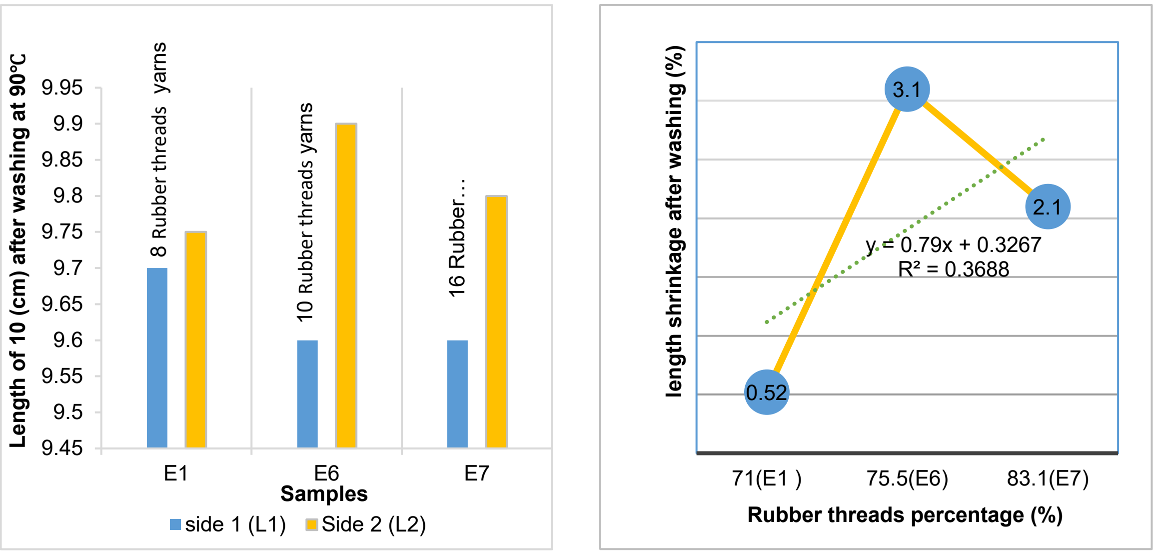
Figure 15. The relation between group 2-A samples' percentage of rubber thread and elongation at maximum load

This non-linear relationship, as shown in Figure (15), suggests that there may be an optimal percentage of rubber thread for achieving both strength and flexibility in the tape. The optimal condition is 83.1% for the narrow tape.

3.2.1.4 The relation between rubber thread percentages and the shrinkage length of 10 cm between the two sides after washing

It is clear from Figure (16-A) that there is a significant difference in length shrinkage between the two sides of the E6 and E7 samples (71% and 83.1% rubber threads) after washing. However, sample E1 shows minimal change in its length after washing

This indicates that the presence of rubber threads affects not only the elongation at maximum load but also the shrinkage properties of the fabric.



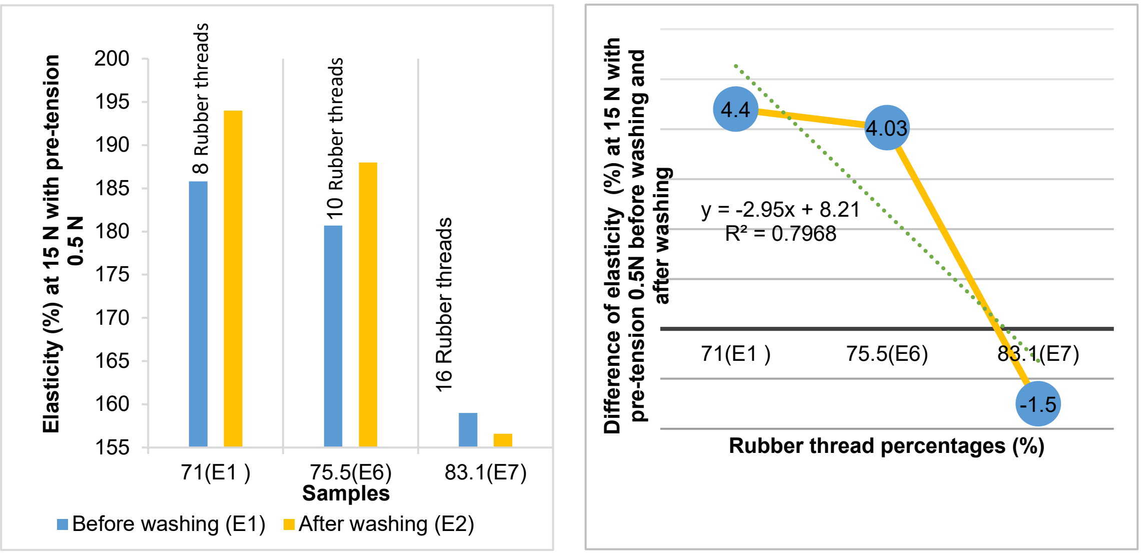
A

B

Figure 16. A Group 2-A samples' length at side 1 and side 2 of each sample after washing versus sample code, B The relation between group 2-A samples' rubber thread percentage and the mean of length shrinkage after washing

3.2.1.5 The relation between rubber thread percentages and the percentage of elasticity at 15 N with pre-tension 0.5 N.

Figure (17-A) illustrates the percentage of elasticity at 15 N with a pre-tension of 0.5 N, before and after washing, for each rubber thread percentage. It is clear from Figure (17-B) that the relationship between the rubber thread percentages and the difference in elasticity at 15 N with a pre-tension of 0.5 N after washing is inversely linear ($R^2 = 0.79$). As the rubber thread percentage increases, the difference in elasticity decreases. Therefore, based on the smallest change in elasticity, the rubber thread percentage of 83.1% is optimal for narrow width.



A B

Figure 17. A The percentage of elasticity at 15 N with Pre-tension 0.5N before and after washing versus group 2-A samples' rubber thread percentage, B The relation between group 2-A samples' rubber thread percentage and the difference in elasticity percentage after washing

3.2.1.6 The relationship between rubber thread percentages and the percentage of tension decay

From Figure (18), it is clear that the relationship between the rubber thread percentage and tension decay is a closed, inverse linear relation with a correlation coefficient ($R^2 = 0.88$). Therefore, at higher rubber thread percentages (83.1%), tension decay improves.

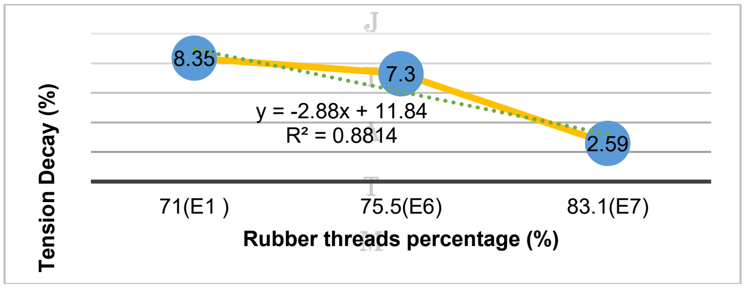


Figure 18. The relation between group 2-A samples' rubber threads' percentage and the tension decay

So, we can obtain these results from the analysis of group 2-A with a narrow tape machine with a width of 1.4 cm:

- The rubber threads' percentage of elastic tape has a significant effect on the tested properties.
- Most of the properties improved by increasing the rubber threads' percentage, up to 83.1%.
- The optimum case is at a rubber thread percentage of 83.1%.

3.2.1.7 Ranking of Elastic Tape Samples in Group 2-A

Radar charts of group 2- A of the elastic tape samples Figure. (19); showed that sample E7 with the higher percentage of rubber threads 83.1% in the same narrow tape width by arranging warp (1poyester yarn:2rubber threads yarn); ranked in first place with the higher radar chart area as it acted higher performance in all samples with different rubber thread percentages in narrow width tape by radar chart area (21460) followed by E1, and E6 as shown in Table (5); that means that in the same width higher percentage of rubber threads is preferred in narrow tape but in calculated limits as there is not a higher difference between radar chart area of sample E1 (Radar chart area= 18599), and E6 (Radar chart area=18566

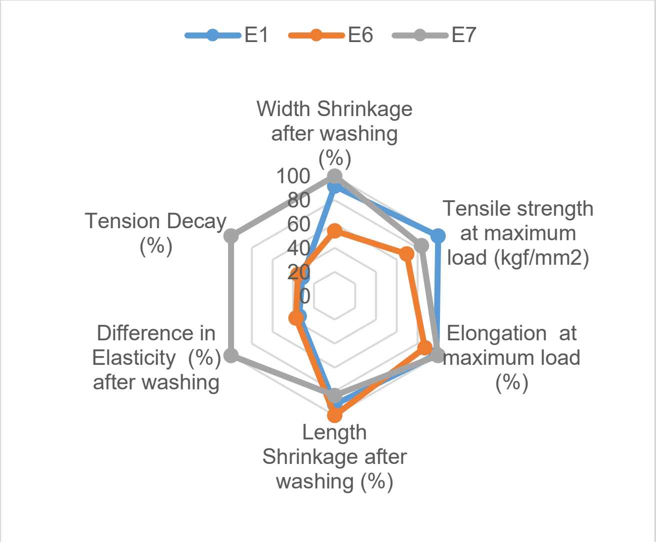


Figure 19. Radar charts of group 2-A samples with different rubber thread percentages in narrow tape width (1.4cm)

Table 5. Radar chart areas of the second sample group 2-A

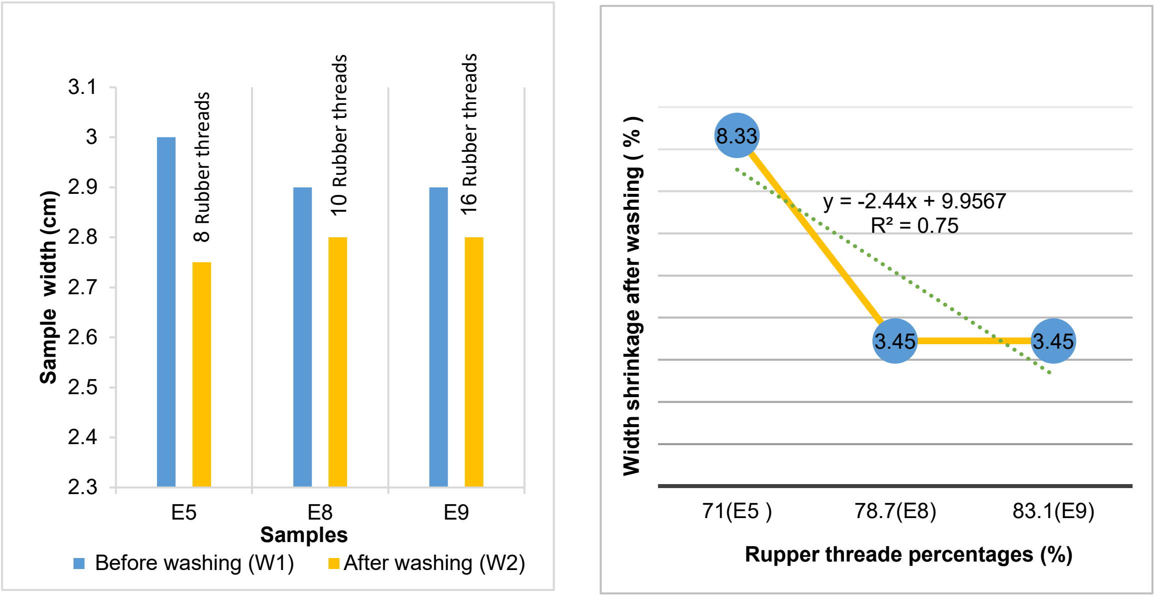
Rank	Sample code	Rubber threads percentage/warp	Radar chart area
1	E7	83.1	21460
2	E1	71	18599
3	E6	75.5	18566

3.2.2 Group (2-B) (Effect of different Rubber thread percentages in the same width used wide-width of 3.1 cm on the machine)

With rubber thread percentages of 71%, 75.5%, and 83.1%, the samples exhibited varying mechanical properties, indicating that the percentage of rubber thread has a significant impact on width shrinkage after washing, elongation at maximum load, percentage of elasticity, and tension decay, but an insignificant impact on tensile strength at maximum load and length shrinkage after washing.

3.2.2.1 The relation between the rubber thread percentages and the width Shrinkage percentage after the washing process

Figure (20-A) shows that there is a difference between tape width shrinkage before and after washing. From Figure (20-B), it is evident that the relationship is inversely linear with a correlation coefficient ($R^2 = 0.75$). This indicates that as the rubber thread percentage increases from 71% to 78.7%, the width shrinkage decreases, but it remains constant beyond this point. Therefore, width shrinkage improves with rubber thread percentages above 78.7%, with the optimal condition being a rubber thread percentage of 83.1%.



A **B**

Figure 20. A Group 2-B samples' width with different rubber thread percentages before and after washing versus sample code, B Relation between group 2-B samples' rubber thread percentages and width shrinkage% after washing

3.2.2.2 The relation between the rubber thread percentages and the tensile strength at maximum load.

From Figure (21), we can notice the relation between the percentage of rubber threads and the percentage of the tensile strength at maximum. load after washing is not linear. The best condition here is 71% of rubber threads.

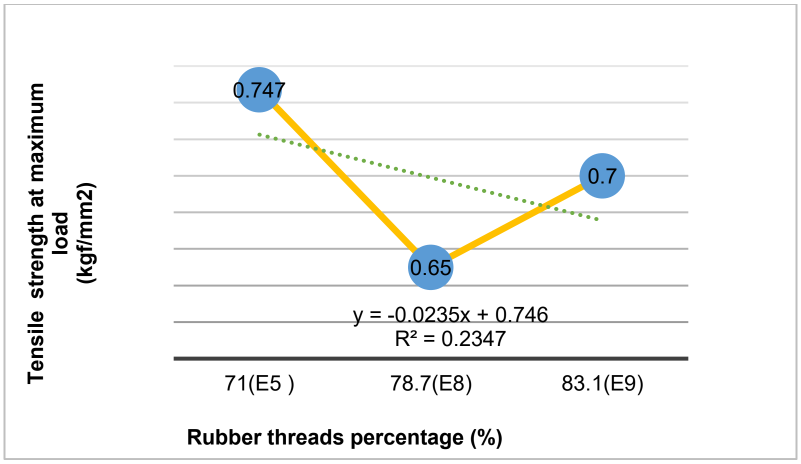


Figure 21. The relation between group 2-B samples' percentage of rubber thread and tensile strength at maximum load

3.2.2.3 The relation between the rubber thread percentages and the elongation at maximum load

Figure (22) shows a direct linear relationship with a correlation coefficient ($R^2 = 0.81$), indicating that as the rubber thread percentage increases, the elongation at maximum load also increases. Therefore, the optimal condition for this property is sample E9 with 83.1% rubber threads.

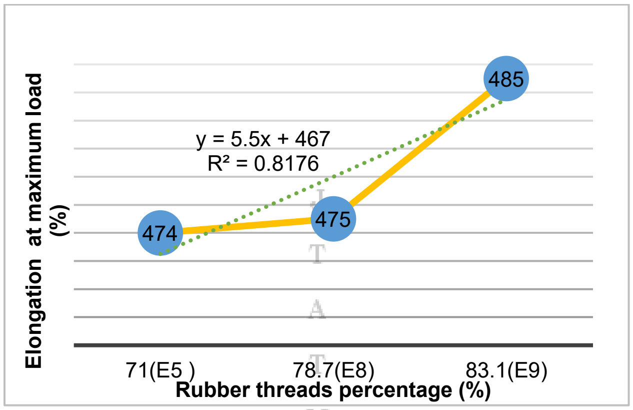
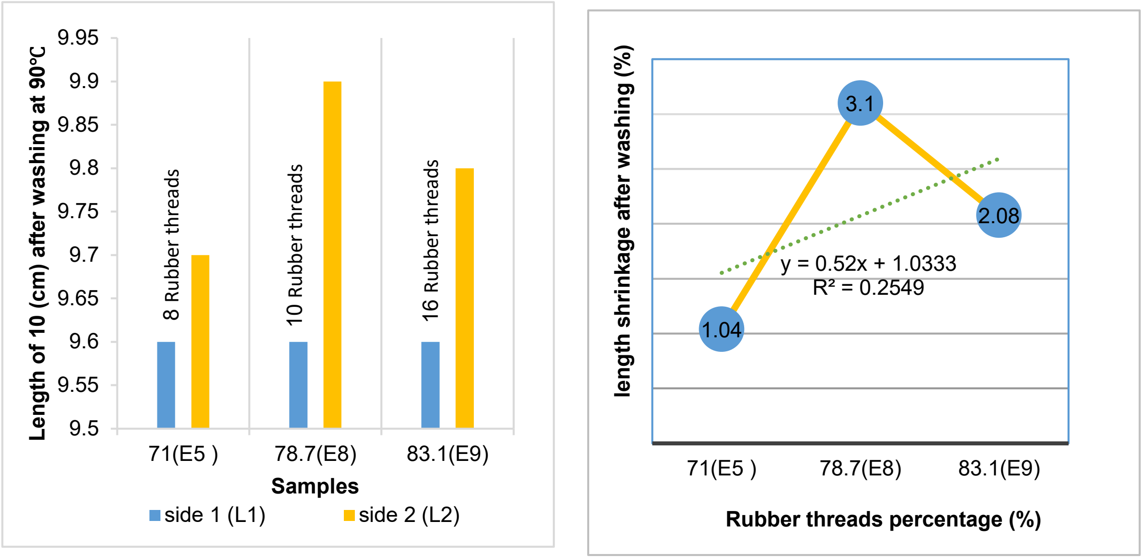


Figure 22. The relation between group 2-B samples' percentage of rubber thread and elongation at maximum load

3.2.2.4 The relation between rubber thread percentages and shrinkage length of 10 cm after washing

As shown in Figure (23-A), there is a clear difference in sample length between the two sides of the elastic tape after washing. Figure (23-B) demonstrates that, In this case, the optimal condition is a rubber thread percentage of 71%, as it exhibits the least difference between the two sides.

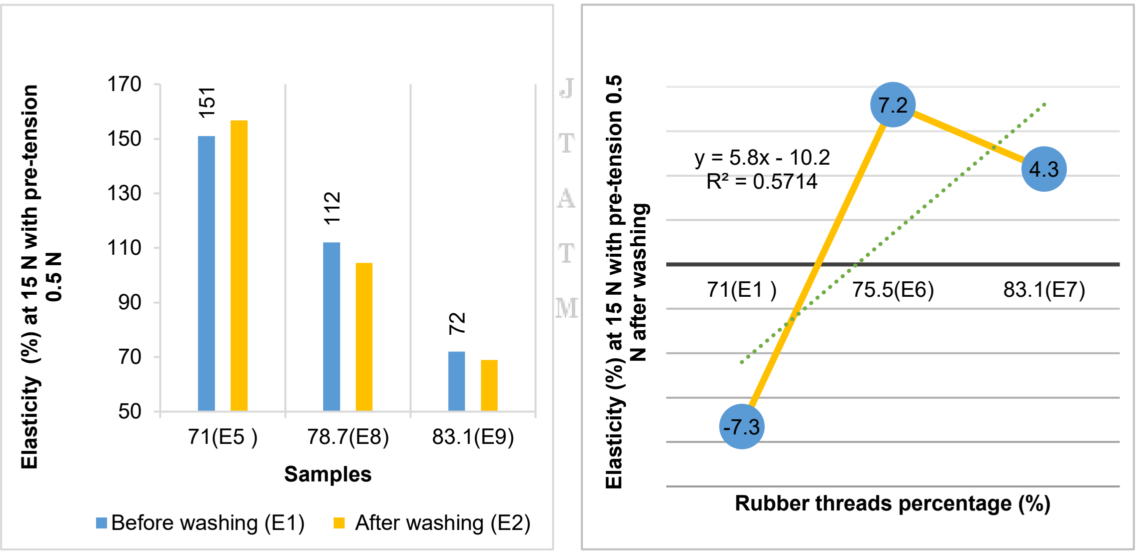


A B

Figure 23. A Group 2-B samples' length at side 1 and side 2 of each sample after washing versus sample code and rubber threads percentage, B The relation between group 2-B samples' rubber thread percentage and the mean of length shrinkage after washing

3.2.2.2 The relation between rubber thread percentages and the percentage of elasticity at 15 N with pre-tension 0.5 N

As shown in Figure (24-A), at 71%, the tape experiences an extension in length after washing, while at 75.5% and 83.1% rubber thread percentages, the tape length contracts after washing. The relationship is not linear. Figure (24-B) clearly shows that the optimal condition is at a rubber thread percentage of 83.1% (E9), where there is the least deformation.



A B

Figure 24. A The percentage of elasticity at 15 N with Pre-tension 0.5N before and after washing versus group 2-B samples' rubber thread percentage, B The relation between group 2-B samples' rubber thread percentage and the difference in elasticity percentage after washing

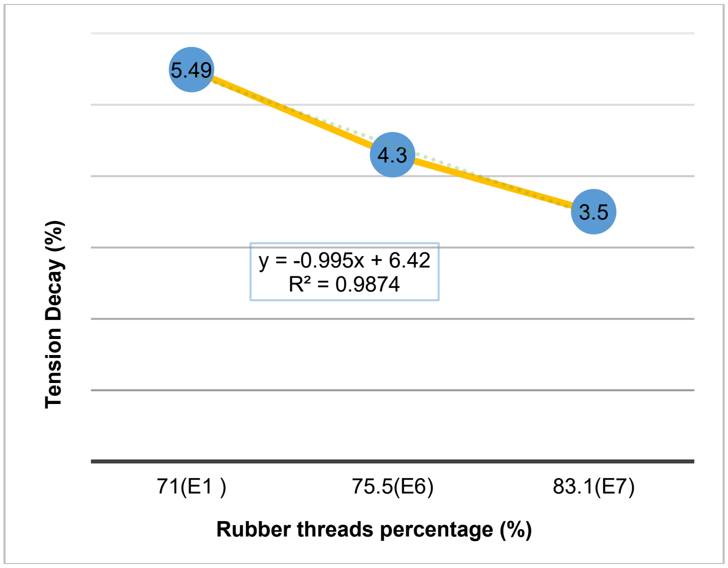


Figure 25. The relation between group 2-B samples' rubber threads' percentage and the tension decay

3.2.2.3 The relationship between rubber thread percentages and the percentage tension decay

As shown in Figure (25), the relationship between the rubber thread percentages and the tension decay is a close, reverse linear correlation ($R^2 = 0.98$). This indicates that as the rubber thread percentage increases, the tension decay decreases. Therefore, the highest rubber thread percentage yields the lowest tension decay. percentage 83.1% will be the best for the tension decay property.

From the analysis of group 2-B with a wide tape width of 3 cm, the following results can be concluded:

- The percentage of rubber threads in the elastic tape significantly affects the tested properties.
- The tensile properties and the shrinkage length percentage between the two sides after washing are optimal at a rubber thread percentage of 71%.
- The other tested properties are improved with a rubber thread percentage of 83.1%.

3.2.2.7 Ranking of Elastic Tape Samples in Group 2-B

Radar charts for group 2-B of elastic tape samples (Figure 26) showed that sample E9, with the highest rubber thread percentage (83.1%) in the same wide tape width (arranged as 1 polyester yarn: 2 rubber thread yarns), ranked first with the largest radar chart area, indicating superior performance compared to other samples. Sample E9 achieved a radar chart area of 22054, followed by E8 and E5, as shown in Table 6. This indicates that, for the same wide tape width, a higher percentage of rubber threads is preferred, although there are limits to the improvement.

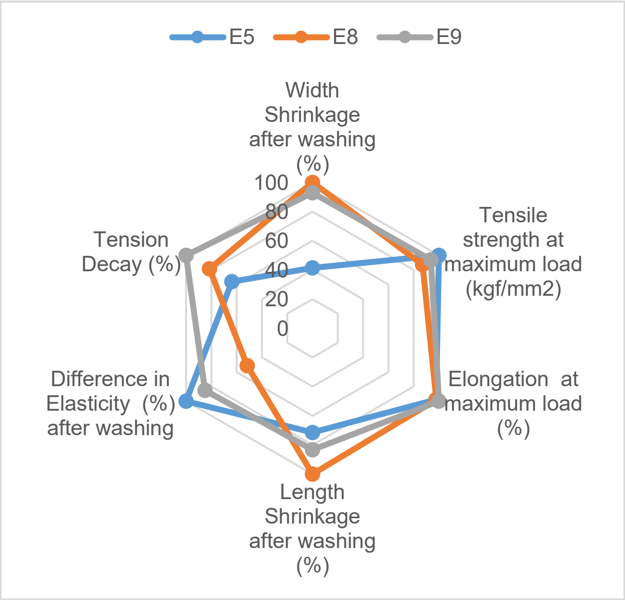


Figure 26. Radar charts of the group 2-B samples with different rubber thread percentages in a wider tape width (3.1 cm)

Table 6. Radar chart areas of the third sample group

Rank	Sample code	Rubber thread percentages /warp	Radar chart area
1	E9	83.1	22054
2	E8	78.7	19138
3	E5	71	15931

3.3 Analysis of variance (ANOVA test) of the elastic tapes

Due to the influence of various variables on the attributes of the obtained samples, an ANOVA test with a 95% confidence level and P-value was conducted, as shown in Table 7. The results revealed that the width of the elastic tape significantly affected several properties of the samples, including width shrinkage after washing, tensile strength at maximum load, elongation at maximum load, length shrinkage after washing, elasticity variation (%) at 15 N with pre-tension 0.5 N, and tension decay percentage. Additionally, the variation in rubber thread percentages (ranging from two to twenty threads) significantly impacted all tested properties for both narrow and wide tape widths.

Table 7. P-values of ANOVA test of elastic tape samples

	ANOVA p-value		
	Different width	**Rubber threads percentage**	
Characteristic		Narrow width tape	Wide width tape
Width Shrinkage after washing (%)	4.6E-223*	1.1E-11*	1.52E-95*
Tensile strength at maximum load (kgf/mm^2)	1.5E-216*	2.22E-92*	1.8E-89*
Elongation at maximum load (%)	2.13E-32*	1.32E-12*	2.43E-06*
Length Shrinkage after washing (%)	1.16E-20*	8.62E-08*	8.36E-07*
Elasticity variation (%) at 15 N with Pre-tension 0.5N	1.23E-30*	0.018403*	3.81E-08*
Tension Decay (%)	4.7E-227*	1.65E-18*	6.09E-92*

***Significant effect using confidence limit 95%**

4. Conclusion

Garment manufacturing needs elastic tapes in many applications such as pants and bras' elastic tapes, but actually these products face aesthetic and durability deformation problems during daily use and washing cycles. This study aimed to find a solution for this deformation. For this purpose, elastic tape samples with varying widths and rubber thread percentages in the warp were produced and tested. The thickness and longitudinal weight of the tapes were measured, and correlation coefficients were calculated to assess the impact of these variables. Radar charts were employed for sample evaluation, and a one-way ANOVA test was conducted. The main findings are as follows:

- Thickness and longitudinal weight of the elastic tapes varied with different widths and rubber thread percentages.
- Elastic tape width significantly impacted its properties, with the 1.5 cm width showing the best mechanical performance.
- Rubber thread percentages also influenced the performance of both narrow and wide elastic tapes. In the narrow-width group (1.4 cm), sample E7, with 83.1% rubber thread, exhibited the highest performance. Similarly, in the wide-width group (3.1 cm), sample E9, also with 83.1% rubber thread, demonstrated superior properties.
- Overall, increasing both the width and rubber thread percentage resulted in improved performance of the elastic tape.
- Based on these findings, it is recommended to use elastic tapes within a width range of 1.5–3.1 cm, as this range optimizes most mechanical properties. Additionally, a rubber thread percentage of 83.1% is ideal to achieve good performance elastic tapes Suitable for use in clothing products, durable and performs well, maintaining its performance after use and washing.

5. Acknowledgments

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References

AATCC TM61, (2020), "Test Method for Colorfastness to Laundering: Accelerated".

Abdel-Megied, Z. M., & Abd El-Aziz, M. Y. (2018). Improve UV Protection Property of Single Jersey for Summer Protective Clothes. In *JTATM* (Vol. 10, Issue 3).

Abdel-Megied, Z. M., Seddik, K. M., El-Aziz, M. Y. A., & El-Gabry, L. K. (2020). The enhancement of the functional properties of polyester microfiber single jersey using some nano-materials. *Egyptian Journal of Chemistry*, *63*(1), 145–154. https://doi.org/10.21608/ejchem.2019.2868.1804

Abeliotis, K., Amberg, C., Candan, C., Ferri, A., Osset, M., Owens, J., & Stamminger, R. (2015). Trends in laundry by 2030. *Household and Personal Care Today*, *10*(5), 22–28.

Abo El Naga, H. T. E. S., & Abd El-Aziz, M. Y. I. (2023). Eco-friendly materials knitting by different yarn ply for high-performance garments. *Research Journal of Textile and Apparel*. https://doi.org/10.1108/RJTA-03-2023-0038

Algamal, G. (2015). The Impact of Elastic Type and Its Fixation Method on Fabrics' Mechanical Properties. *Journal of American Science* , *11*(11). http://www.threadsmagazine.com

ASTM D3776, (2017), "Standard test methods for mass per unit area (weight) of fabric", ASTM International, PA, available at: www.astm.org.

ASTM D1777, (2019), "Standard test method for thickness of textile materials", ASTM International, PA, available at: www.astm.org.

ASTM D3759/D3759M-05 (2019), "Standard Test Method for Breaking Strength and Elongation of Pressure-Sensitive Tape", ASTM International, PA, available at: www.astm.org.

Bin Samsuri, A. (2010). Degradation of natural rubber and synthetic elastomers. In *Shreir's Corrosion* (pp. 2407–2438). Elsevier. https://doi.org/10.1016/B978-044452787-5.00117-7

BS 4952(2.2), (1992), "Elastic Fabrics Test Methods", SAI Global.

BS 4952(2.3), (1992), "Elastic Fabrics Test Methods", SAI Global.

Cesa, F. S., Turra, A., Checon, H. H., Leonardi, B., & Baruque-Ramos, J. (2020). Laundering and textile parameters influence fibers release in household washings. *Environmental Pollution*, *257*. https://doi.org/10.1016/j.envpol.2019.113553

Darwish, H. M., Abdel-Megied, Z. M., & Abd El-Aziz, M. Y. (2023). Designing composite poly-amide cord knitted fabrics for reinforcing concrete beams. *Journal of the Textile Institute*. https://doi.org/10.1080/00405000.2023.2222895

Davuluri, S., & Ravipati, A. (2022). A Study on the Stretching Behavior of Rubber Bands. *Journal of Emerging Investigators* , 5, 1–6. www.emerginginvestigators.org

Distler, D. (2001). Polymer Dispersions. In K. Jürgen Buschow, R. W. Cahn, & P. Veyssière (Eds.), *Encyclopedia of Materials: Science and Technology* (pp. 7272–7275). Elsevier.

Dong, Y., Yao, X., & Xu, X. (2021). Cross section shape optimization design of fabric rubber seal. *Composite Structures*, *256*. https://doi.org/10.1016/j.compstruct.2020.113047

Dorgham, M. el saeed, Mohamed, R. A. E. hady, & Tahoon, E. S. M. S. A. (2019). Effect of Different Constructions of Elastic Bands Produced by Crochet Warp Knitting Machine On its Functional Properties as Clothing. *Journal of Architecture, Arts, and Humanistic Scinces*, *5*(19), 471–507. https://doi.org/10.12816/mjaf.2019.14366.1221

El-Aziz, M. Y. A., Abdel-Megied, Z. M., & Seddik, K. M. (2023). Enhancement Reinforcing Concrete Beams Using Polypropylene Cord-Knitted Bars. *Tekstilec*, *66*(1), 64–72. https://doi.org/10.14502/tekstilec.66.2022108

El-Aziz, M. Y. A., Mohamed, A. A., & Mustafa, E. (2024). Effect of abrasion level on surface handling and thermal conductivity of blended suit fabrics. *Journal of the Textile Institute*. https://doi.org/10.1080/00405000.2024.2369730

El-Moursy, A. M., Abdel Mageid, Z. M., Abd El-Aziz, M. Y. I., Asser, N., & Hakeim, O. (2023). Evaluating fabrics produced by blending hollow fibres and bamboo with cotton/polyester wastes using the Kawabata system. *Research Journal of Textile and Apparel*. https://doi.org/10.1108/RJTA-01-2023-0005

Elsayed, E. W., Emam, M. F., Abd El-Aziz, M. Y., el Naga, H. T. E. S. A., & Emara, L. H. (2025). Regenerated cellulose fibers for preparation of alginate and lornoxicam-loaded medical knitted textiles: A response surface optimization study. International Journal of Biological Macromolecules, 321. https://doi.org/10.1016/j.ijbiomac.2025.146360

Eom, R. i., & Lee, Y. (2021). Characterization of Elongation Behavior According to Sewing Conditions for Elastic Bands on Woven Fabrics. *Journal of the Korean Society of Clothing and Textiles*, *45*(4), 648–660. https://doi.org/10.5850/JKSCT.2021.45.4.648

Gent, A. N. (2005). Rubber Elasticity: Basic Concepts and Behavior. In *Science and Technology of Rubber* (Third Edition, pp. 1–27). https://doi.org/10.1016/B978-012464786-2/50004-3

ISO 139, (2005),"Textiles-standard atmospheres for conditioning and testing", available at: www.iso.org.

ISO 6330, (2021), "Textiles-Domestic washing and drying procedures for textile testing", available at: www.iso.org.

Jacobs, C. A. M., Abdelgawad, A. M., Jockenhoevel, S., Ito, K., & Ghazanfari, S. (2023). Warp-knitted fabric structures for a novel biomimetic artificial intervertebral disc for the cervical spine. *Journal of Materials Science*, *58*(21), 8940–8951. https://doi.org/10.1007/s10853-023-08544-x

James, H. M., & Guth, E. (1943). Theory of Rubber Elasticity for Development of Synthetic Rubbers. *Rubber Chemistry and Technology*, *16*(2), 286–289. https://doi.org/10.5254/1.3540115

Karaca, E., Omeroglu, S., & Becerir, B. (2015). Effects of Fiber Cross-sectional Shapes on Tensile and Tearing Properties of Polyester Woven Fabrics. *TEKSTİL ve KONFEKSİYON*, *25*(4), 313–318. https://www.researchgate.net/publication/298849242

Kirstein, T., & Rodel, H. . (2000). Methods for testing stretch tapes. *E170-E171*, *81*(9), 736–737.

Kyzymchuk, O., Marmaralı, A., Melnyk, L., Oğlakcıoğlu, N., Ertekin, G., Cüreklibatır Encan, B., Arabuli, S., & Arabuli, A. (2023). The effect of weft yarn type and elastomer yarn threading on the properties of elastic warp knitted fabrics. Part II: Thermal comfort properties. *Journal of Engineered Fibers and Fabrics*, *18*. https://doi.org/10.1177/15589250231171582

Markova, I. (2019). Synthetic Fibers. In *Textile Fiber Microscopy* (pp. 123–160). Wiley. https://doi.org/10.1002/9781119320029.ch5

Morgham, A. E. H., Abd El-Aziz, M. Y. I., El-Fallal, A. A., & El Sayed Abo El Naga, H. T. (2023). Utilizing Sustainable KOMBUCHA Laminated with Knitted and Woven Cellulosic Fabrics for Anti-microbial Headboard. *Egyptian Journal of Chemistry*, *66*(13), 2101–2117. https://doi.org/10.21608/EJCHEM.2023.227405.8373

Perumal, V., Palanivel, S., & Thulaseedharan, A. (2013). Natural rubber producing plants: An overview. *Article in AFRICAN JOURNAL OF BIOTECHNOLOGY*. https://doi.org/10.5897/AJBX12.016

Pocius, A. V. (2012). 8.12- Adhesives and Sealants. In M. Moeller & K. Matyjaszewski (Eds.), *Polymer Science: A Comprehensive Reference* (1st Edition, pp. 305–324). Elsevier.

R. Lozada, E., Gutiérrez Aguilar, C. M., Jaramillo Carvallho, J. A., Sánchez, J. C., & Barrera Torres, G. (2023). Vegetable Cellulose Fibers in Natural Rubber Composites. In *Polymers* (Vol. 15, Issue 13). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/polym15132914

Salman, D. M., & Abd El-Aziz, M. Y. I. (2025). Effect of Titanium Nano-Silicate Treatment on Functional and Appearance of Garment Linen Fabrics Blended with Cotton. *Egyptian Journal of Chemistry*, *68*(3), 525–538. https://doi.org/10.21608/ejchem.2024.301071.9933

Salman, D. M., & El-Aziz, M. Y. I. A. (2024). Effect of an Eco-friendly Treatment on Water Resistance of Knitted Cellulosic Fabrics. *Egyptian Journal of Chemistry*, *67*(1), 89–99. https://doi.org/10.21608/EJCHEM.2023.225457.8316

Seddik, K. M., Ali, M. A., Yahia, S., & El-Aziz, M. Y. A. (2025). Examine integrating PCM yarns for enhancing merchant maritime uniform fabricated by polyester double cloth fabric. *Scientific Reports*, *15*(1), 32551. https://doi.org/10.1038/s41598-025-18093-9

Scheid, F., Lambert, E., Maitra, W., Niestrath, M., Fäh, D., Portmann, C., Gorny, S., & Stamminger, R. (2016). Textile quality depletion due to household machine wash - Ways to measure and impacts of wash duration and temperature on textiles. *Tenside, Surfactants, Detergents*, *53*(5), 438–444. https://doi.org/10.3139/113.110462

Seddik, K. M., & Ali, M. A. (2022). Characterization the Performance of Elastic Band Using Different Polyester Microfiber Cross-Sections and Stitch Densities. *Egyptian Journal of Chemistry*, *65*(8), 549–556. https://doi.org/10.21608/ejchem.2022.111259.5062

Sethulekshmi, A. S., Saritha, A., & Joseph, K. (2022). A comprehensive review on the recent advancements in natural rubber nanocomposites. In *International Journal of Biological Macromolecules* (Vol. 194, pp. 819–842). Elsevier B.V. https://doi.org/10.1016/j.ijbiomac.2021.11.134

Setiyana, B., Ismail, R., & Jamari, J. (2021). *Effect of Rubber Deformation Along Sliding Contact on Its Stress and Friction Force: A Numerical Investigation*.

Setiyana, B., Ismail, R., Jamari, J., & Haryanto, I. (2021). *Mechanical Properties Identification of Vulcanized Rubber by Using Mooney-Rivlin Method*.

Setiyana, B., Sugiyanto, Jamari, J., & Khafidh, M. (2018). Numerical investigation on the elastic modulus of rubber-like materials by a rigid ball indentation technique. *MATEC Web of Conferences*, *204*. https://doi.org/10.1051/matecconf/201820407002

Shawky, M. M., El-Gabry, L. K., & El-Aziz, M. Y. A. (2024). Analytical Study of Comfortability, Dyeability, and UPF of Sports Wear Interlock Fabrics. *Egyptian Journal of Chemistry*, *67*(13), 259–285. https://doi.org/10.21608/ejchem.2024.227403.9025

Spencer, D. J2001) .). *Knitting Technology: A Comprehensive Handbook and Practical Guide*.

Surajarusarn, B. (2020). *Performance improvement of natural rubber composites reinforced with pineapple leaf fiber*. Université de HauteAlsace-Mulhouse;MahidolUniversity.

Wang, W., Liu, B., & Kodur, V. (2013). Effect of Temperature on Strength and Elastic Modulus of High-Strength Steel. *Journal of Materials in Civil Engineering*, *25*(2), 174–182. https://doi.org/10.1061/(asce)mt.1943-5533.0000600

Yip, J. (2016). Narrow fabric elastic tapes Get rights and content. In *Advances in Women's Intimate Apparel Technology* (pp. 25–35). Woodhead Publishing Series in Textiles. https://doi.org/10.1016/B978-1-78242-369-0.00002-5

Zhang, S., Yick, K. lun, Chen, L., Yu, W., Lau, N., & Sun, Y. (2020). Finite-element modelling of elastic woven tapes for bra design applications. *Journal of the Textile Institute*, *111*(10), 1470–1480. https://doi.org/10.1080/00405000.2019.1704962

Zhao, Y. H., Guo, Y. Z., Wei, Q., Topping, T. D., Dangelewicz, A. M., Zhu, Y. T., Langdon, T. G., & Lavernia, E. J. (2009). Influence of specimen dimensions and strain measurement methods on tensile stress-strain curves. *Materials Science and Engineering: A*, *525*(1–2), 68–77. https://doi.org/10.1016/j.msea.2009.06.031