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# Investigate the Effects of different Yarn Counts on the Properties of Kevlar 29 for Multifunction Applications

**Doaa H. Elgohary *, Dina M. Hamoda , Sarah Yahia**

*Department of Spinning and Weaving Engineering, Textile Research and Technology Institute, National Research Centre, 33 El Bohouth st., Dokki, P.O.12622, Cairo, Egypt.*

**Abstract**

Kevlar 29 is considered one of the aramid fibers. It is primarily used in applications that require strength and durability, such as ballistic protection, and body armor for military and law enforcement personnel. It is also used in the aerospace and automotive industries to reinforce composite materials, as well as in various industrial applications. The objective of this work is to study and investigate the effect of using different yarn counts on the properties of Kevlar samples according to their functional performance efficiency. In this research, two different Kevlar samples were used with the same fabric density and weave structure (plain 1/1) and different yarn counts); ten different mechanical and physical properties (weight, thickness, tensile strength, elongation, stiffness, air permeability, puncture resistance, thermal conductivity, stiffness, and spray test) were conducted to approve its functional performance efficiency. The influence of different mechanical properties was statistically analyzed using an independent t-test with a significant difference at a P-value of 0.05. The radar plot was calculated and analyzed to identify the best properties that were evaluated for samples 1 and 2; a radar map was used to determine the best location for samples. performing samples. The results showed that all variables were significantly affected by yam count except for water permeability, which had no significant impact. All properties were evaluated for calculation, and 2; a radar map was used to determine the best location for samples. The area of the radar plot was calculated showing that sample 1 performed best, followed by sample 2.

***Keywords:*** High-performance; Cooper Lithium Silicate; Independent t-test; Thermal Conductivity; Technical Textiles.

## 1. Introduction

Technical textiles are types of fabric materials that are produced on a large scale for their execution and technical characterization, unlike other types of textiles that are made for their aesthetic properties [1]. Technical textiles have been developed in many trends, both in the industry and in market segments with different levels of prosperity [2]. Technical applications differ from one area to another according to their properties, including military, aerospace, agricultural, medical textiles, and sport textiles like fencing sport suits [3], to meet specific requirements depending on fabric parameters such as yarn count, fabric count, material used, and fabric structure [4,5].

Technical textiles are characterised by porosity, durability, strength, and flexibility, as they are designed to meet different requirements depending on the textile parameters used, such as material, yarn count, weave structure, and twist factors for warp and weft yarns [6]. In the same way high-performance fibers appear, they are important industrial components for many different applications. Understanding the relationship between properties and performance of various high-tech and high-performance fibers to improve mechanical properties with dimensional stability of structural morphology

*Corresponding author e-mail: doaaelgohary34@gmail.com. (D. H. Elgohary)
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has been the subject of numerous research projects over the past decades [7].
Kevlar is one of the high-performance synthetic fibers that was developed in 1965 by two researchers, Stephanie Kwolek and Herbert Blades. The two scientists worked for the DuPont company. Their product offered a number of benefits that led to its commercial launch in the early 1970s [8].

Kevlar fibers are widely used due to their properties such as high strength, abrasion resistance, flammability resistance, very low elasticity, light weight, toughness, and corrosion resistance [9]. Although Kevlar is characterised by its protection, it loses some of its strength after being exposed to ultraviolet rays [10].

There is more than one type of Kevlar; one of them is Kevlar 29 fibers which have high strength and stiffness, but on the other hand, Nylon 6.6 have greater ductility. By mixing these fibers in resin prior to molding, the resulting hybrid composite can be mechanically superior to the corresponding single-fiber type composites. The contribution of the viscoelastically generated preload via the commingled nylon fibers should lead to a further increase in performance [11].

It has good properties such as light weight, non-flammability, and high temperature resistance. It is suitable for use in brake pads, armour for vehicles, cables, and other industrial applications [12]. Due to the insufficient amount of existing research on Kevlar and the challenges associated with acquiring this particular material, the present study aims to investigate and analyzed the impact of employing various yarn counts on the properties of Kevlar 29 for multifunction applications.

## 2. Materials and Method

### 2.1. Methodology

Two Kevlar samples (1 and 2) were used with areal density 223, 419 g/m$^2$ and thickness 0.3266, 0.561 mm respectively; the yarns are from DuPont- USA. The same yarn count was used for sample 1 at both warp and weft direction as thin yarn count, while different counts were used for sample 2 as more thick yarn count than sample 1, as presented in Table 1. The two samples were coated using lithium silicate (CLS).

The physical, mechanical, comfort and thermal properties were investigated for two Kevlar samples. First the samples were incubated in an incubator according to standard test methods ASTM D1776 [13]. Subsequently, all properties were carried out according to the standard test methods as follows:

a. Areal density was conducted according to standard test method ASTM D3776 [14], three replicates were taken from each sample.

b. Fabric thickness was executed according to standard test method ASTM D1777 [15], ten readings were taken as a replicate for each sample.

c. Tensile Strength and Elongation were measured according to standard test method ASTM D5035 [16] using a Galdabini tester, three readings were taken as a replicate for sample 1 and 2.

d. Puncture Resistance was applied according to standard test method ASTM D4833 [17] Galdabini tester was used to measure the samples, three replicates were taken for each sample.

e. Air permeability was measured according to standard test method ASTM D737 a SDL ATLAS M021A tester was used to measure the sample [18], three readings were observed from each sample.

f. Stiffness of fabrics was conducted for both direction warp and weft according to standard test method ASTM D1388 [19]; three replicated were measured for samples 1 and 2.

g. Spray test was measured according to standard test method AATCC 22 [20], three replicates were taken from samples 1 and 2.

h. Water Permeability was conducted according to ASTM D4491 [21], three replicates were taken from samples 1 and 2.

### 2.2. Thermal Conductivity

Samples were measured using KES-F7 Thermo Labo based on stated thermal conductivity in accordance with BS 4745 [22]. The measurement technique is based on heat transfer through the sample from a hot plate with a temperature of 30 °C to another plate with a temperature of 20 °C, with the difference between the recorded temperatures being 10 °C [23].

**Table 1. Samples characterization**

| Sample Code | Warp Density /Inch | Weft Density/Inch | Weave Structure | Warp Count (Tex) | Weft Count (Tex) | Areal Density ($g/m^2$) | Thickness (mm) |
|---|---|---|---|---|---|---|---|
| Sample 1 | 16 | 16 | Plain 1/1 | 164 | 164 | 223 | 0.326 |
| Sample 2 | 16 | 16 | | 356 | 311 | 419 | 0.561 |

### 2.3. Ultraviolet Protection Factor (UPF)

The UV protection factor (UPF) percentage blocking values of the samples were calculated as average values and measured according to the standard test method AATCC 183 [24], using the UV spectrophotometer (JASCO V-750) to measure the test.

The physical and mechanical properties were executed in the Department of Spinning and Weaving Engineering; also, some tests were carried out at the Scientific Competence Center for Textile Laboratories and the Central Unit for Analysis and Scientific Services of the National Research Centre.

### 2.4. Statistical Analysis for Properties

The mean results were tabulated, presented as bar graphs, and discussed. The effects of various mechanical properties were statistically analyzed using an independent significant difference t-test at P value ($p = 0.05$) using IBM SPSS Statistics Version 22 for Windows (SPSS Inc., IBM Corporation, NY, USA). . The radar plot was calculated and evaluated to identify the best performing samples.

### 2.5. Scanning Electron Microscope

A Zeiss Sigma 500 VP Analytical FE-SEM scanning electron microscope (SEM) was used to measure the surface morphology of Kevlar samples. The acceleration voltage for samples was measured at 30 kV. The samples were mounted on aluminum stubs (coated by Edward, UK) then an S150A sputtering system was used to sputter coat the samples with a layer of gold.

### 2.6. Fourier Transform Infrared Spectroscopy

A Fourier transform infrared spectrometer (JASCO FTIR-4700, Japan) was used to measure the samples. The samples were then prepared with a keratin powder on the spectrometer in a range between 400-4000 cm-1 [25].

### 2.7. Contact Angle

The OCA-15EC (Dataphysics Gmbh, Germany) with software was used to measure the water contact angle according to standard test method ASTM D5946 [26]. The test was measured with 10 µL drops of triple-distilled water.

## 3. Result and Discussion

In this research, different properties were used studied to two Kevlar coated samples; the mechanical and physical properties of the samples were examined. The mean and standard deviation values for replicates were evaluated and displayed. The result data was estimated from an independent t-test at the significant level at the p-value ($p=0.05$), the radar chart was calculated, scored and presented to identify the best performing samples.

### 3.1. Properties Analysis

### 3.1.1. Tensile Strength Property

From the statistical analysis of the tensile strength for Figure 1 and Table 2, it was found that sample 2 had the best result in warp and weft directions than sample 1. This may be due to the weft count being higher than the warp count. On the other hand, analysis of the t-test showed that the tensile strength in the warp and weft directions was significantly affected by the yarn count in both directions at P-value ($p=0.001$) and ($p=0.000$), respectively.

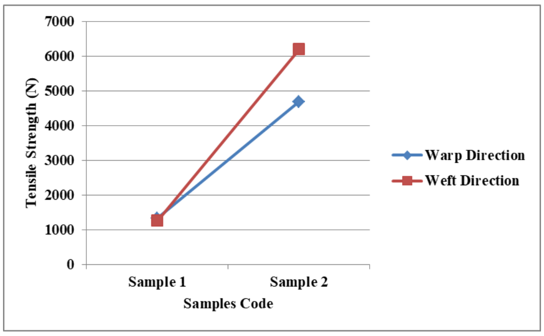



**Figure 1. Tensile Strength for Samples at Warp and Weft Directions.**

### 3.1.2. Elongation Property

Analysis of the elongation property from the Figure 2 and Table 2 showed that the samples in the warp direction had the highest result for both samples. This may be due to the fact that elongation is inversely proportional to the tensile property. In addition, from the T-test analysis, it was suggested that the property was significantly affected by yarn count in both directions at the P-value ($p$=0.000) for both directions.

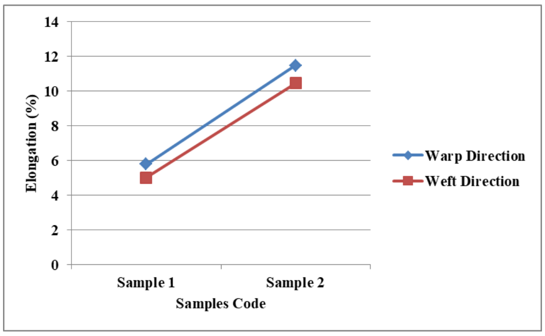



**Figure 2. Elongation for Samples at warp and Weft Directions.**

### 3.1.3. Puncture Resistance Property

From Figure 3 and Table 2, it can be seen that sample 2 showed the highest results than sample 1, which is due to the yarn count for sample 2 being higher than sample 1. On the other hand, using the statistical t-test analysis for samples, the property was shown to be significant at the P-value ($p$=0.000).

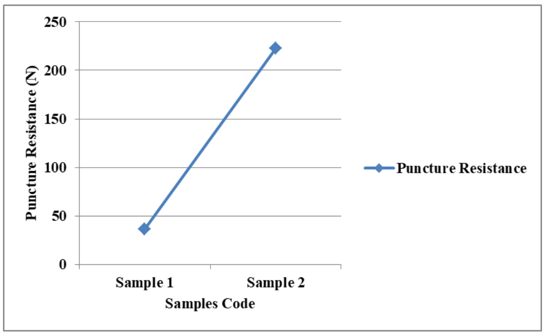



**Figure 3. Puncture Resistance for Samples.**

### 3.1.4. Spray Test Property

According to the statistical analysis of Figure 4, Table 2 and as the test depend on the appearance evaluation, the result of sample 1 equals to 100 which show there is no absorption of water, while sample 2 results equal to 50 which show as it absorbed about 75 of water.

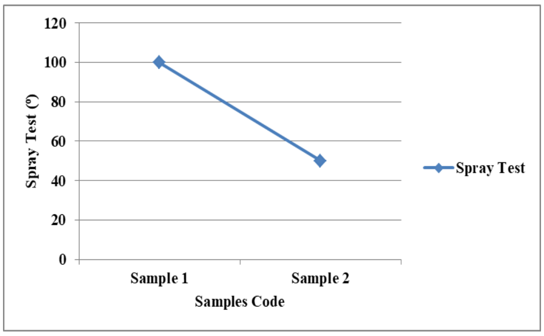



**Figure 4. Spray Test for Samples.**

### 3.15. Water Permeability Property

Based on the water permeability property, it was shown from Figure 5 and Table 2 that sample 1 achieved the best result than sample 2. This can be attributed to the fact that the yarn count in sample 2 is higher than in sample 1, which led to a reduction in the inter spaces between the yarns and a reduction in the flow of water through the fabric. In addition, analysis of the t-test revealed that the property was not significant for either sample at the P-value ($p$=0.837).

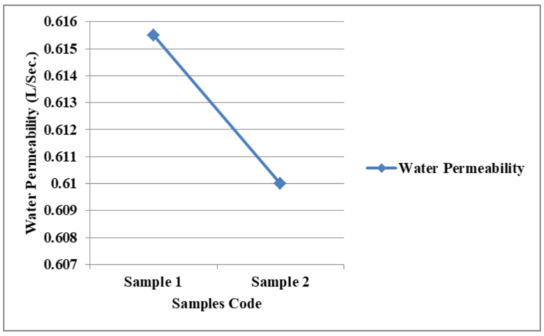



**Figure 5. Water Permeability for Samples.**

### 3.1.6. Air Permeability Property

When analyzing the air permeability variables, it was observed from Figure 6 and Table 2 that sample 1 performed the best than sample 2, which is due to the yarn count of sample 2 being greater than that of sample 1, resulting in a reduction in the spaces between the yarns, resulting in a reduction in airflow through the fabric. On the other hand, in the statistical analysis of the t-test, a significant effect on the air permeability property was found at the P value ($p$=0.000).

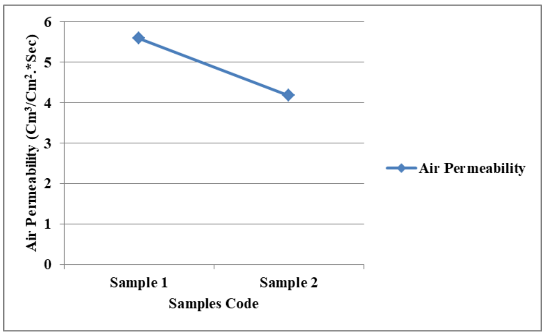



**Figure 6. Air Permeability for Samples.**

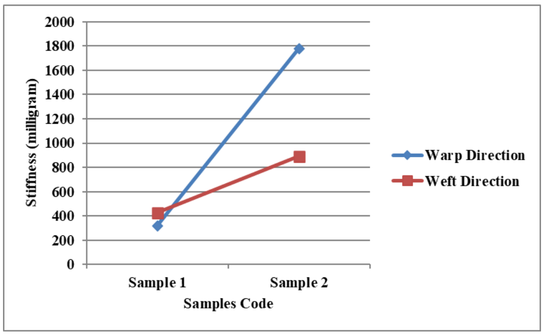



**Figure 7. Stiffness for Samples at Warp and Weft Directions.**

### 3.1.7. Stiffness Property

Using the stiffness variables, it was shown from Figure 7 and Table 2 that Sample 2 performed better than Sample 1; this can be interpreted as the yarn count is increased for Sample 2 compared to Sample 1, resulting in an increase in fabric stiffness for Sample 2 compared to Sample 1. Also, statistical analysis of the t-test shows a significant effect for the stiffness variable for both directions at the P-value ($p$=0.000).

### 3.2. Thermal Conductivity

The samples were tested to examine the effect of the thermal conductivity test on the samples as shown in Table 3; the results showed that S1 performed best in terms of thermal conductivity than S2, which means that S2 has better thermal insulation ability than S1. According to statistical analysis of the independent t-test Table 2, it was shown that there was a significant effect on the thermal conductivity variable for both samples at P-value (p=0.000).

**Table 2. Data Analysis for Samples**

| Variables | Sample 1 | Sample 2 | t-Value | P-Value |
|---|---|---|---|---|
| | Mean ± S.D. | | | |
| Tensile Strength at Warp Direction (N) | 1338.17 ± 265.3 | 4695.9 ± 579.5 | 9.125 | 0.001* |
| Tensile Strength at Weft Direction (N) | 1260.3 ± 174.0 | 6209.3 ± 327.6 | 23.106 | 0.000* |
| Elongation at Warp Direction (%) | 5.79 ± 0.77 | 5.00 ± 0.29 | 11.644 | 0.000* |
| Elongation at Weft Direction (%) | 11.47 ± 0.34 | 10.46 ± 0.32 | 21.652 | 0.000* |
| Puncture Resistance (N) | 36.65 ± 6.72 | 222.76 ± 3.34 | 60.776 | 0.000* |
| Spray Test ($^0$) | 100 ± 0 | 50 ± 0 | ------ | ------ |
| Water Permeability (L/Sec.) | 0.62 ± 0.05 | 0.61 ± 0.03 | 0.219 | 0.837$^{ns}$ |
| Thermal Conductivity (W/Cm.°C) | 2.65 ± 0.01 | 1.99 ± 0.01 | 159.217 | 0.000* |
| Air Permeability ($Cm^3/Cm^2$*Sec.) | 5.59 ± 0.12 | 4.17 ± 0.04 | 19.122 | 0.000* |
| Stiffness at Warp Direction (milligram) | 302.6 ± 35.6 | 1780 ± 0 | 83.000 | 0.000* |
| Stiffness at Weft Direction (milligram) | 462.8 ± 169.49 | 890 ± 123.32 | 4.076 | 0.000* |

**Note: Means values were presented at p<0.05 for various properties were (*) = Significant, (ns) = Non-significant.**

**Table 3. Result of the thermal conductivity of the sample ± S.D.**

| Samples Code | Thermal conductivity ($Wm^{-1}K^{-1}$) |
|---|---|
| **S1** | **2.645 ± (0.0003386)** |
| **S2** | **1.995 ± (0.00044765)** |

( ) – the values in brackets indicate the standard deviation.

### 3.3. Ultraviolet Protection Factor

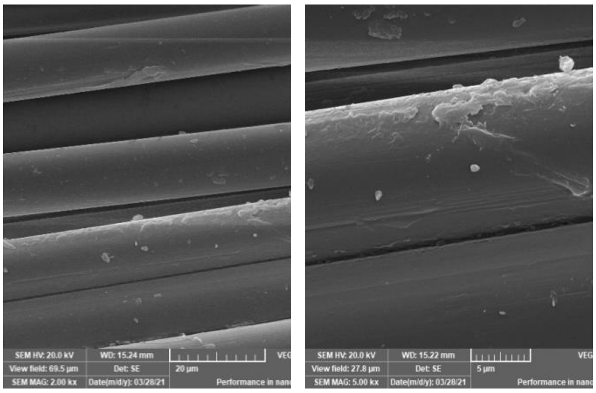
UV protection factor (UPF) blocking percentage analysis was performed, average values were calculated (Table 4), UV spectrophotometer (JASCO V-750) was used to measure UPF value. The fabric's ability to protect against UV radiation is determined by its UPF, with higher levels of protection corresponding to higher UPF ratings of 50+. The UPF ratings for Kevlar samples increase to the level equivalent to a UPF rating of 50+, which is the best UV protection.

**Table 4. UPF Values for Kevlar Samples**

| | **S1** | **S2** |
|---|---|---|
| **UPF** | **147.333** | **139.9** |

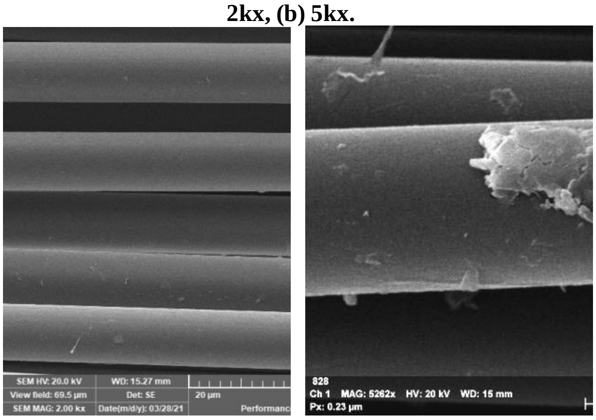
### 3.4. Fabric Morphology Measurement

The material morphology of the samples was measured using a scanning electron microscope; the samples were shown at 2000x magnification (Figures 8 and 9). The measurement represents the surface area of fibers with a smooth surface for both samples.



(a) (b)

**Figure 8. Scanning Electron Microscope Sample 1 at (a) 2kx, (b) 5kx.**



(a) (b)

**Figure 9. Scanning Electron Microscope Sample 2 at (a) 2kx, (b) 5kx.**

### 3.5. Fourier Transform Infrared Spectroscopy Measurement

Based on standard references, the FTIR spectra in the wavelength range 400- 4000 $cm^{-1}$ [27]. Figure 10 illustrates FT-IR spectra of polyamide (Kevlar) coated with copper lithium silicate (CLS). The characteristic broad peaks of the OH stretch mode (3355 $cm^{-1}$) and N-H (3000 $cm^{-1}$) of coated Kevlar are replaced by broad peaks upon increasing the $ZrO_2$ concentrations in the (CLS) matrix. The two peaks at 2923 $cm^{-1}$ and 2845 $cm^{-1}$ were assigned to the CH2 (CH3) stretching frequencies of the polymer chain and their intensities decrease with increasing $ZrO_2$ ion. The peaks around 1000 - 1250 $cm^{-1}$ attributed to the bond vibration of Si-O-Si and Si-O-M (where M = Cu, Li and Zr) and their intensity depend on the ZrO2 ion content in the copper-lithium-silicate matrix. The vibrational peaks at 450- 645 $cm^{-1}$ were attributed to MO in silicate due to the flexural vibrational peaks of Si-O-Si and Si-O-M in the 450-1150 $cm^{-1}$ range, confirming that CLS/Zr accumulated on the Kevlar surfaces.

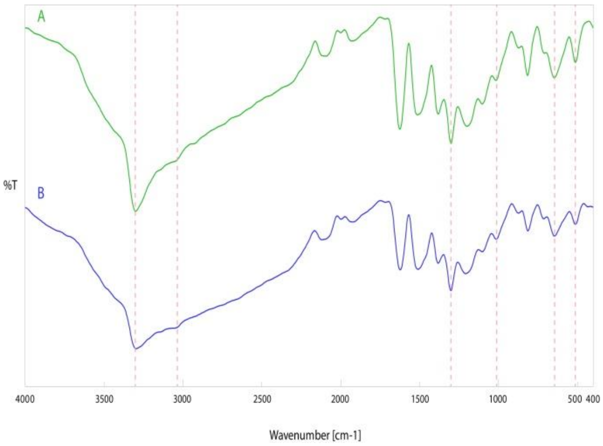
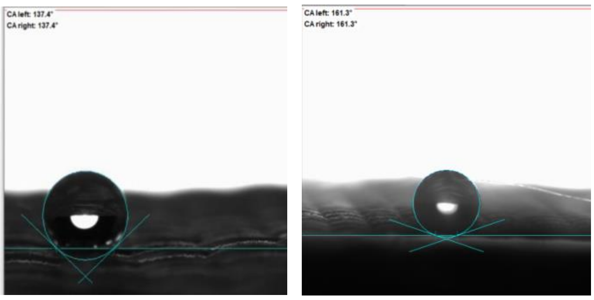



**Figure 10. FTIR for Kevlar Samples.**

### 3.6. Contact Angle Measurement

Figure 11 shows the measurement of the water contact angle of both Kevlar samples; Sample 1 has a value of 137.4 because this contact angle measure is for the hydrophobic type sample. While Sample 2 had a value of 161.3, which corresponds to superhydrophobicity, this means that when a water droplet is scattered on the surface, it has a very small rolling angle.



(a) (b)

**Figure 11. Contact Angle for Samples (a) 1 and (b) 2.**

### 3.7. Properties Evaluation using Radar Chart

All properties were evaluated for Samples 1 and 2. A radar chart was used to determine the best location for the samples as shown in Figures 12, 13 and Table 5. The area of the radar plot was calculated and shows that Sample 1 performed best, followed by Sample 2.

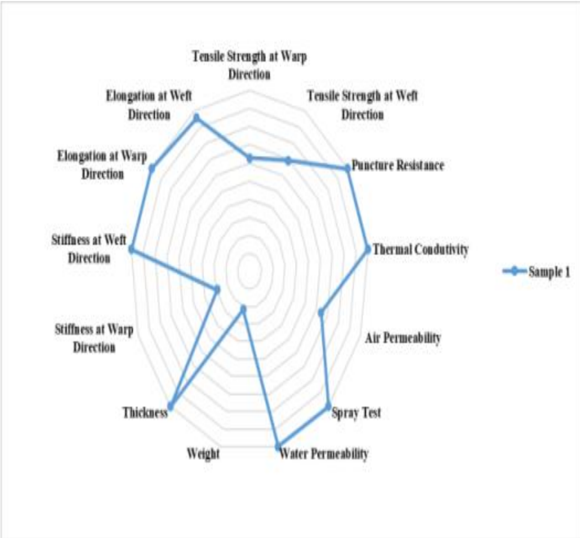



**Figure 12. Radar Chart for Sample 1.**


**Figure 13. Radar Chart for Sample 2.**

**Table 5. Radar Area for Samples**

| Samples Code | Radar Area |
|---|---|
| Sample 1 | 72198.8 |
| Sample 2 | 71882.1 |

## 4. Conclusion

The development and use of technical textiles is constantly evolving, driven by advances in materials science, manufacturing technologies and the demand for innovative solutions in various industries. Kevlar 29 is a type of aramid fiber developed by DuPont. It is a high-performance material known for its exceptional strength and resistance to impact, abrasion and heat. In this study, two different Kevlar samples with the same weave density and weave structure 1/1 coated with copper lithium silicate (CLS) were used, the warp and weft count for samples 1 was the same, it differs in sample 2. Ten properties were studied to examine functional power efficiency.

Analysis of the results using an independent t-test revealed a significant difference in yarn count for all variables except the water permeability variable. The radar plot was evaluated and presented to identify the best performing samples.

The radar diagram and radar area for samples 1 and 2 were measured, evaluated and calculated. It was found that Sample 1 performed the best, followed by Sample 2. Scanning Electron Microscopy (SEM) and Fourier were used to measure the surface morphology of the samples. Transformed infrared spectroscopy was performed on both samples.

## 5. Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, author-ship, and/or publication of this article.

## 6. Acknowledgement

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## 7. References

[1] Elgohary, D. H., Hawas, H.S., Enhancing the Comfort Properties of Military Clothing using Phase Change Materials (PCMs) and Bamboo. *Journal of the TEXTILE Association*, **2021**. 82, 1, 26 -34.

[2] Elgohary, D.H., et al., Evaluate the Impact of UVB Radiation on different High Performance Fabrics Treated with Nanomaterials. *Egyptian Journal of Chemistry*, **2019**. 62, 12, 1-10. https://doi.org/10.21608/ejchem.2019.11040.1709.

[3] S. Yahia et al, Enhancing Functional Performance of Sportswear Fabrics Using Polyester Micro-Fibers Yarns. *Journal of Textile Association*, **2018.** 79, 4, 266 - 275. ISSN 0368-4636. e-ISSN 2347-2537.

[4] Fayed, A.I.H., Abo El Amaim, Y.A., Elgohary, D.H., Enhancing the Performance of Cordura and Ballistic Nylon using Polyurethane Treatment for Outer Shell of Bulletproof Vest. *Journal of King Saud University- Engineering Sciences*, **2023.** 35, 239 -246. https://doi.org/10.1016/j.jksues.2021.02.001.

[5] Elgohary, D.H., Yahia, S., Seddik, K.M., Characterization the Properties of Blended Single Jersey Fabrics using Different Microfiber Yarn Cross-sections and Gauges Machine. *Egyptian Journal of Chemistry*. **2021**. 64, 6, 3041-3048. https://doi.org/ 10.21608/ejchem.2021.58596.3265.

[6] Abdelghaffar, R.A., Hamoda, D.M., Elgohary, D.H., Surface Coatings of Polyester Fabrics using Titanium Dioxide and Zinc Oxide for Multifunctional Medical Applications. *The Journal of Textile Institute*, **2021.** 13, 12 2621 -2633. https://doi.org/10.1080/00405000.2021.2001892.

[7] Avci, H., et al., High Performance Fibers: A Review on Current State of Art and Future Challenges. *Journal of Engineering and Architecture Faculty of Eskisehir Osmangazi University*, **2019.** 27, 2, 130 -155. https://doi.org/10.31796/ogummf.537704.

[8] Kabir, R. B., Ferdous N., Kevlar-The Super Tough Fiber. *International Journal of Textile Science*, **2012.** 1, 6, 78 -83. DOI: 10.5923/j.textile.20120106.04.

[9] Elgohary, D. H., Elshakankery, M. H., Analysis of the Mechanical Properties of Kevlar 29 Woven Fabrics. *Journal of the TEXTILE Association*, **2020.** 80, 6, 441 -447. ISSN 0368-4636. E- ISSN 2347-2537.

[10] Saad, M.A., et al., Effect of using Trilobal® Polyester on the Functional Performance of Fencing Suit. *Research Journal of Textile and Apparel*, **2021.** 25, 1, 1-18. https://doi.org/10.1108/RJTA-08-2019-0035.

[11] Fazal, A., Fancey, K. S., Performance enhancement of nylon/kevlar fiber composites through viscoelastically generated pre-stress. *Polymer Composites*, **2014.** 35, 931-938. https://doi.org/10.1002/pc.22737.

[12] Nair, A. N., Sundharesan, S., Mohammed Al Tubi, I. S., Kevlar-based Composite Material and its Applications in Body Armour: A Short Literature Review. *Materials Science and Engineering*, **2020.** 1-9. DOI:10.1088/1757-899X/987/1/012003.

[13] ASTM D1776/D1776M, Standard Practice for Conditioning and Testing Textiles. **2020.** ASTM International, available at: www.astm.org.

[14] ASTM D3776/D3776M, Standard Test Methods for Mass per Unit Area (Weight) of Fabric. **2020**. ASTM International, available at: www.astm.org.

[15] ASTM D1777, Standard Test Methods for Thickness of Textile Materials. **2019**. ASTM International, available at: www.astm.org.

[16] ASTM D5035, Standard Test Methods for Breaking Force and Elongation of Textile Fabrics (Strip Method). **2019**. ASTM International**,** available at: www.astm.org.

[17] ASTM D4833, Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products. **2007**. ASTM International**,** available at: www.astm.org.

[18] ASTM D737, Standard Test Methods for Air Permeability of Textile Fabrics. **2012**. ASTM International, available at: www.astm.org.

[19] ASTM D1388, Standard Test Methods for Stiffness of Fabrics. **2012**. ASTM International**,** available at: www.astm.org.

[20] AATCC 22, Spray Rating Tester (Water Repellency Tester). **2005**.

[21] ASTM D4491, Standard Test Methods for Water Permeability of Geotextiles by Permittivity. **1999a**.

[22] BS 4745, Determination of Thermal Resistance of Textiles. **1971**, London: British Standards Institute.

[23] Hawas, H. S., Elgohary, D. H., Effect of the Construction Elements on the Mechanical Properties of Military Clothes. *Journal of the Textile Association*, **2023.** 83, 5, 303 -309. https://doi.org/10.56716/4/1449.

[24] AATCC-183, Transmittance or Blocking of Erythemally Weighted Ultraviolet Radiation through Fabrics. **2004**.

[25] Guibaud G., et al., Relation between extracellular polymers' composition and its ability to complex Cd, Cu and Pb. *Chemosphere*. **2003.** 52, 10, 1701 -1710. https://doi. org/10.1016/S0045-6535(03)00355-2.

[26] ASTM D5946, Measuring the Water Contact Angle on Surface-treated Polymer Films.

[27] Smith B. C., Fundamentals of Fourier transform infrared spectroscopy. **2011.** CRC Press.