BMBAD BJESR Mühendislik Bilimleri ve Araştırmaları Dergisi
Journal of Engineering Sciences and Researches

Electromagnetic Shielding Measurement of Hybrid Pique Fabric in the X-Band

X-Band Frekansında Hibrit Pike Kumaşın Elektromanyetik Kalkanlama Ölçümü

[1]Ediz ERDEM

[1]*Karabük Üniversitesi, Elektrik-Elektronik Mühendisliği, Mühendislik Fakültesi, Karabük, Türkiye*

edizerdem@karabuk.edu.tr

Araştırma Makalesi/Research Article

ARTICLE INFO

Article history

Received : 18 October 2024
Accepted : 29 November 2024

Keywords:

Hybrid, Pique Fabric, X-Band, Waveguide, Measurement

ABSTRACT

This study measured and evaluated the electromagnetic shielding effectiveness (EMSE) of hybrid pique knitted fabrics produced using 50 µm thick copper conductor wire and cotton yarn in the X-band frequency range (8-12 GHz). The study used a waveguide measurement system to determine the effect of shielding performance at different fabric wale densities. The hybrid pique fabric has immense potential for practical use in high-frequency electromagnetic shielding applications with its lightweight, flexible, and cost-effective structure. The fabric's ability to block electromagnetic waves by reflection and absorption, its suitability for wearable technology, and its ease of production make it an attractive alternative to traditional, heavier shielding materials such as metals. The ease of production, cost-effectiveness, and adaptability suggest that this fabric will be widely used in advanced communication systems, defense applications, and next-generation wearable electronics.

MAKALE BİLGİSİ

Makale Tarihleri

Gönderim : 18 Ekim 2024
Kabul : 19 Kasım 2024

Anahtar Kelimeler:

Hibrit, Pike Kumaş, X-Bant, Dalgakılavuzu, Ölçüm

ÖZET

Bu çalışmada, 50 µm kalınlığında bakır iletken tel ve pamuk ipliği kullanılarak X-bant frekans aralığında (8-12 GHz) üretilen hibrit pike örme kumaşların elektromanyetik ekranlama etkinliği ölçülmüş ve değerlendirilmiştir. Çalışmada, farklı kumaş fitil yoğunluklarında ekranlama performansının etkisini belirlemek için bir dalga kılavuzu ölçüm sistemi kullanılmıştır. Hibrit pike kumaş, hafif, esnek ve uygun maliyetli yapısıyla yüksek frekanslı elektromanyetik ekranlama uygulamalarında pratik kullanım için büyük bir potansiyele sahiptir. Kumaşın yansıma ve soğurma yoluyla elektromanyetik dalgaları engelleme yeteneği, giyilebilir teknoloji için uygunluğu ve üretim kolaylığı, onu metaller gibi geleneksel, daha ağır ekranlama malzemelerine çekici bir alternatif haline getirmektedir. Üretim kolaylığı, uygun maliyet ve uyarlanabilirlik, bu kumaşın gelişmiş iletişim sistemlerinde, savunma uygulamalarında ve yeni nesil giyilebilir elektroniklerde yaygın olarak kullanılacağını düşünülmektedir.

ORCID: [1]0000-0003-1901-2055

1. INTRODUCTION

Nowadays, electromagnetic applications are rapidly increasing and becoming more and more involved in our lives with the development of technology. While these developments offer innovative solutions, especially in communication, energy, and health, electromagnetic waves also adversely affect human health and the environment. Accordingly, the importance of electromagnetic shielding studies is increasing to protect against the harmful effects of electromagnetic fields. Materials that can absorb and/or reflect electromagnetic waves have been designed for electromagnetic shielding. These materials are divided into three main categories: metals, carbon-based materials, and polymer composites. Metals (copper, aluminum, steel, etc.) stand out with their ability to reflect and scatter electromagnetic waves thanks to their high conductivity. However, they have some limitations due to their heavy and inflexible structures. Carbon-based materials (carbon nanotubes, graphene) provide advantages with their light and flexible structures but have disadvantages such as high production costs. Polymer composites are light and flexible materials that provide electromagnetic shielding effectiveness (EMSE) with conductive polymers and metal additives. They offer practical solutions that can be used in wearable technologies and flexible electronics [1-8].

Among the materials used for EMSE, textiles have become increasingly important in recent years due to their wearability. Textile structures are formed by incorporating conductive metal cables, carbon-based materials, and conductive polymers into textile yarns. Textile-based EMSE materials have many advantages over other materials. While lightness and flexibility facilitate using these materials in wearable technologies and personal protective clothing, features such as breathability and comfort provide a great advantage, especially in long-term use. In addition to offering a price advantage over other EMSE materials, ease of production, low cost, a wide range of applications, and the ability to provide aesthetic and functional solutions make textile-based materials stand out in areas requiring electromagnetic protection [9-14].

The X-band is a frequency band covering the range of 8.0 to 12.0 GHz and is used in wide-band communications ranging from radar systems to satellite communications and space research. Especially in military radar applications, the X-band has a high-frequency structure and, therefore, low wavelength. Therefore, it can detect small targets quickly and with high resolution. The X-band is widely preferred in military communications due to its high security and durability [15-18].

In this study, hybrid pique fabric formed by adding 50 µm thick copper conductor wire was produced, and EMSE values were measured at X-band frequencies. In the X-band frequency region, it is aimed to be a simple production and cost-effective solution in a wearable structure to be used in radar navigation, satellite communication, environmental applications, stealth technology, wearable devices, new generation flexible electronic products, and military applications. Different wale densities (12.5, 25, 50) 1/10 cm were produced in the hybrid pique fabric structure. The effects of the produced fabrics on EMSE were measured experimentally in the waveguide measurement setup in the 8-12 GHz frequency. The absorption and reflection results obtained were examined, and the EMSE value was calculated. The experimental results obtained were analyzed and discussed.

2. MATERIALS AND METHOD

2.1 Shielding Effectiveness

The EMSE consists of three components: reflection, absorption, and transmission. When the EMSE of hybrid pique fabric wants to measure hybrid pique textile material and the free space impedance is different, part of the incident electromagnetic wave is reflected. EM waves penetrating the hybrid pique fabric cause surface currents to on the conductive copper in the material. These currents create ohmic losses and are converted into heat, which is defined as absorption. Electromagnetic shielding effectiveness (EMSE) expresses the ability of a material to block or attenuate electromagnetic waves. A represents the absorption capacity of the material, and R represents the reflection capacity of the material. EMSE calculation [10, 19, 20] is given in equation 1.

$$S = A + R \text{ (dB)} \quad (1)$$

Accurate assessment of electromagnetic shielding is difficult with direct measurement, especially at high frequencies. Therefore, it is common to use S-parameters in these frequency ranges. These parameters vary with frequency and provide important information to evaluate the shielding properties of the material. They are calculated using the S_{11} and S_{21} parameters obtained from the vector network analyzer (VNA) using the absorption and reflection of the material. The absorption (A) of the materials is calculated by equation 2.

$$A = 10log\left[\frac{10^{\frac{S_{21}}{10}}}{1-10^{\frac{S_{11}}{10}}}\right] \quad (2)$$

Here, parameter S_{21} represents the transmission coefficient measured by the network analyzer, and S_{11} represents the reflection on the material. The reflectance (R) of materials is calculated by equation 3.

$$R = 10log\left[1 - 10^{\frac{S_{11}}{10}}\right] \quad (3)$$

2.2 Fabrication of Pique Hybrid Yarns

Pique fabric is a type of fabric that is usually woven from cotton yarns and has checkered or diamond-shaped relief patterns in its texture. Pique fabric has a unique structure due to its weaving technique and fabric structure. Cotton yarn is usually used in knitting and is produced by knitting the warp and weft yarns in a certain order and density. During the production phase, the thickness and pattern density of the fabric change according to the type of yarn to be used and the knitting density. Pique fabric has a wide range of uses and is preferred, especially in summer months, with its light and breathable structure, and is frequently used in home textiles such as duvet covers, pillowcases, and bedspreads [21-25]. In the production of pique knitted fabric, 50 µm thick copper conductive wire and cotton yarn were fed into the machine together using Faycon CKM-01-S and Passap Duomatic 80 machines. Copper material was preferred because it has a high conductivity value and is more cost-effective than other conductors. When a 50 µm thick copper conductor is used, the copper conductor can be easily shaped, and there is no breakage during production. In this way, it provides flexibility and light structure. Information on the hybrid fabric produced is given in Table 1.

Table 1. Hybrid pique fabric features

Fabric	Metal Content (%)	Yarn Number (Nm)	Wale Density (1/10 cm)	Course Density (loops/cm)	Cotton Tex (g/km)	Thickness (mm)
Pique	11˜ 14	7.06	50	3	140	1.43
	11˜ 14	7.06	25	3	140	1.43
	11˜ 14	7.06	12.5	3	140	1.43

The photograph of the produced hybrid pique fabric structure is given in Figure 1. Copper wires are visible in the structure.

Figure 1. Produced copper hybrid pique fabric.

2.3 Experimental Measurement Setup

The waveguide measurement system is a high-frequency measurement method used to evaluate the performance of structures that guide the transmission of electromagnetic waves. This method is performed using network analyzers to understand the effects of factors such as dimensions, shape, and material properties. The measurement system usually helps determine losses, reflection coefficients, and transmission efficiency by analyzing wave modes within the waveguide. The waveguide measurement setup consists of a WR90 waveguide, coaxial cable, and a VNA, a 2-port measurement system. The experimental waveguide measurement setup is given in Figure 2. To make accurate measurements, TRL (Through-Reflect-Line) calibration was performed [26]. The calibration method consists of through, reflect, and line stages. In the through stage, two waveguides are directly connected, and measurement is made. In the reflection stage, reflection measurement is made using metal plates in two port arrays. In the line stage, an n(λ/4) line is added between two waveguides, and measurement is taken. The schematic representation of TRL calibration is given in Figure 3. This calibration method is performed to eliminate measurement errors, make precise measurements and to increase measurement reliability. After the calibration is completed, the system's accuracy is verified with known materials. After the verification, the reflection and absorption coefficients are taken from the VNA using the S-parameters obtained from the experimental measurement. The received S-parameters show how much of the transmitted power is reflected and how much is transmitted. These S-parameters are very important for characterizing microwave and RF devices. Analyzing these parameters allows us to determine how they respond to electromagnetic waves and their material properties.

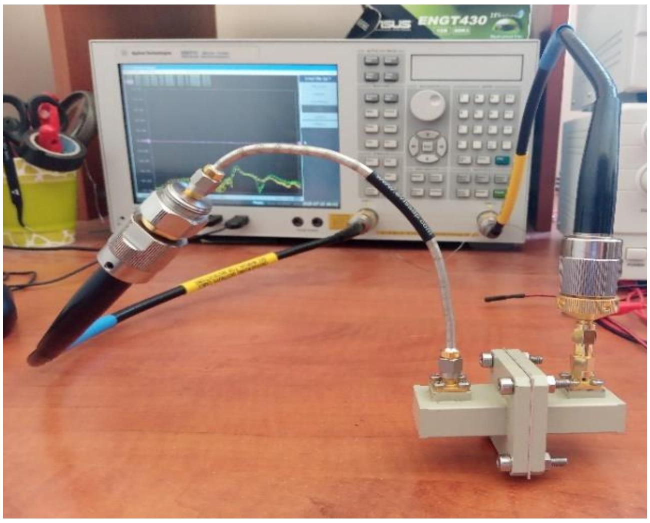

Figure 2. Experimental measurement setup.

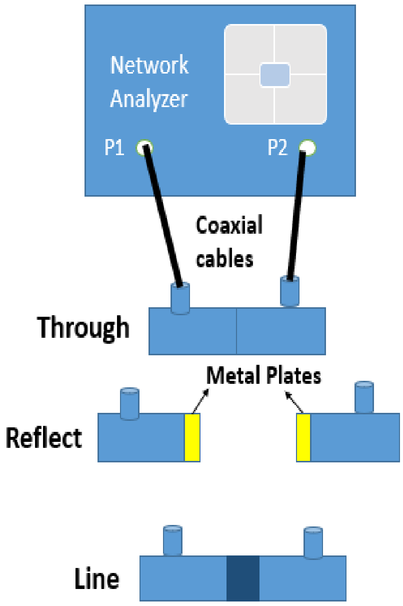

Figure 3. TRL calibration.

After the calibration stages are completed, hybrid pique fabric is placed between two waveguides, and measurements are taken in the 8-12 GHz frequency range. The S-parameters obtained from the VNA are calculated using EMSE calculation formulas. In this way, the EMSE values of the hybrid pique fabric are found depending on the frequency.

3. RESULTS AND DISCUSSION

The EMSE values of the hybrid pique fabric structure in the 8-12 GHz frequency range were calculated by the S-parameters expressing the reflection and transmission coefficients from the waveguide measurement system. The reflection measurement results of hybrid pique fabric, which vary depending on the wale density, are given in Figure 4.

As the density of the wale decreases, the loop dimensions also decrease. Accordingly, the amount of reflection increases. The reflection occurs thanks to the copper wire used in the hybrid fabric structure. The absorption measurement results of hybrid pique fabric, which vary depending on the wale density, are given in Figure 5.

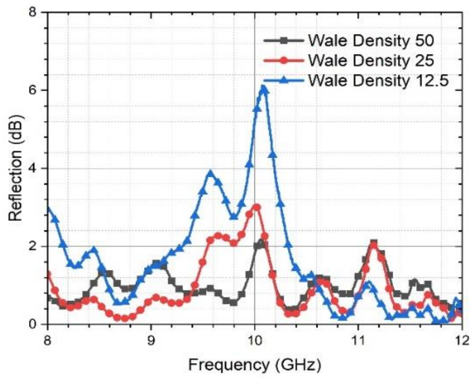

Figure 4. The reflection measurement result of hybrid pique fabric.

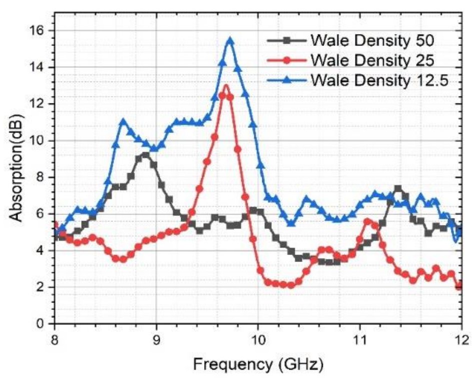

Figure 5. The absorption measurement result of hybrid pique fabric.

It is observed that the amount of absorption increases as the density of the wale decreases. According to the reflection rate, more absorption is obtained in the hybrid pique fabric structure. Absorption occurs by converting the currents formed on the copper wire in the hybrid pique fabric structure into heat. The EMSE value of the hybrid pique fabric, which is the sum of the absorption and reflection amounts at varying wale densities in the 8-12 GHz frequency, is shown in Figure 6. In the measurement results, the wale density was changed to 12.5, 25, and 50, and the change's effect on the EMSE value was investigated. The EMSE value is formed as the sum of absorption and reflection values. In the hybrid pique fabric structure, it is seen that the EMSE value is mostly due to absorption. This can be attributed to the relationship between the loop size and wavelength, where smaller loops better interact with the electromagnetic waves. In general use, the EMSE value between 10 dB and 20 dB is considered good, while between 7 dB and 10 dB is considered the moderate value [27].

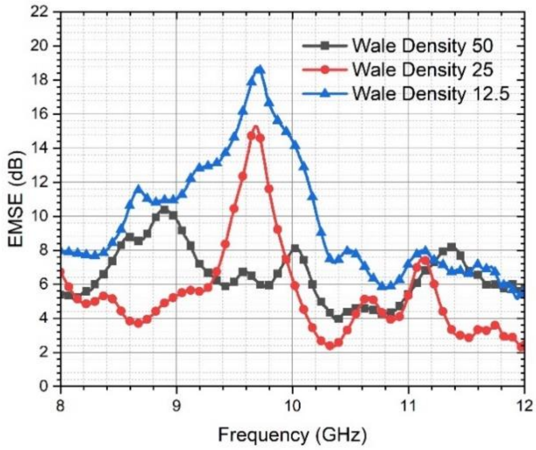

Figure 6. EMSE measurement result of hybrid pique fabric.

It is seen that the hybrid pique fabric with a wale density of 50 has an average EMSE value in the 8-12 GHz frequency band. When the wave density is set to 25, it is observed that it increases by 10 dB and provides a good EMSE value in the range of 9.5-9.84 GHz. When the wave intensity is changed to 12.5, it is seen that the area above 10 dB increases and provides a good EMSE value in the range of 8.6-10.2 GHz. It is observed that the EMSE value increases in a certain frequency range and decreases in other frequency ranges when the wave density changes. It is thought that this phenomenon is caused by the relationship between the wavelength and the dimensions of the pique fabric structure and that the pique fabric formed in the layered structure increases the reflection coefficient.

The study shows that the wale density of the hybrid pique fabric has a significant effect on its electromagnetic shielding performance. As the wale density decreases, the fabric exhibits higher reflection and absorption values, leading to better overall EMSE. This is because smaller loop dimensions in the fabric structure allow for more effective interaction with electromagnetic waves, enhancing both reflection and absorption. The results also suggest that the hybrid pique fabric performs well in the X-band frequency range (8-12 GHz), which is critical for applications such as radar systems, satellite communications, and military devices. In particular, the fabric with a wale density of 12.5 exhibited the highest EMSE values, making it a strong candidate for use in environments requiring robust electromagnetic shielding. Moreover, the hybrid structure of the fabric, combining copper conductor wire with cotton yarn, offers a lightweight and flexible solution, making it suitable for wearable technologies and other applications where traditional metal-based shielding materials would be impractical due to their rigidity and weight.

4. CONCLUSION

In this study, the electromagnetic shielding effectiveness of hybrid pique fabrics in the X-band frequency range (8-12 GHz) and the effect of different wale densities on the shielding performance were investigated. Experimental measurements were taken at various wale densities (12.5, 25, 50) of hybrid fabrics produced using copper conductor wire, and cotton yarn and the results showed that the wale density had a significant effect on the EMSE values. Hybrid pique fabrics with lower wale densities showed higher EMSE values and it was seen that these values changed in frequency ranges depending on the structural properties of the fabric. As the wale density decreased, the loop sizes of the fabric also decreased, and as a result, it was found that it had more absorption value in the reflection of electromagnetic waves. The hybrid pique fabric with a wale density of 12.5 showed the highest EMSE performance in the frequency range of 8.6-10.2 GHz, and the EMSE values exceeded 10 dB in this band. The high EMSE of hybrid pique fabrics values obtained are primarily due to absorption, as the copper wires in the hybrid fabric structure absorb electromagnetic waves and convert them into heat. This absorption, combined with the fabric's lightweight, flexible, and breathable properties, makes hybrid pique fabric a promising candidate for wearable technology and personal protective clothing. Unlike traditional metal-based shielding materials, which are often heavy and rigid, hybrid pique fabric offers a more practical and cost-effective solution with additional advantages such as flexibility and comfort. The level of EMSE performance will allow the fabric to be used in general applications requiring electromagnetic shielding, such as radar systems, satellite communications and military technology, environmental monitoring systems, and wearable electronics. The ability to customize the fabric's EMSE performance by adjusting the wale density will further increase its versatility in different areas.

Future studies could explore the performance of this fabric in higher frequency bands or wider frequency ranges, further expanding its application scope.

Author Contribution

Ediz ERDEM contributed to all stages of the study.

Conflict of Interest

The author has declared no conflict of interest.

REFERENCES

[1] J.S. Roh, Y.S. Chi, T.J. Kang, and S.W. Nam, "Electromagnetic Shielding Effectiveness of Multifunctional Metal Composite Fabrics," Text. Res. J., vol. 78, no. 9, pp. 825–835, 2008.

[2] D. Wanasinghe and F. Aslani, "A review on recent advancement of electromagnetic interference shielding novel metallic materials and processes," Compos. Part B Eng., vol. 176, no. June, p. 107207, 2019.

[3] S. Khasim, "Polyaniline-Graphene nanoplatelet composite films with improved conductivity for high performance X-band microwave shielding applications," Results Phys., vol. 12, pp. 1073–1081, 2019.

[4] Z. Yang, H. Peng, W. Wang, and T. Liu, "Crystallization behavior of poly(ε-caprolactone)/layered double hydroxide nanocomposites," J. Appl. Polym. Sci., vol. 116, no. 5, pp. 2658–2667, 2010.

[5] R. Kumar et al., "Recent progress on carbon-based composite materials for microwave electromagnetic interference shielding," Carbon N. Y., vol. 177, pp. 304–331, 2021.

[6] A.O. Kizilçay and Y. Akinay, "Equivalent analytical model of plain weave composite fabric for electromagnetic shielding applications," J. Microw. Power Electromagn. Energy, vol. 54, no. 3, pp. 245–253, 2020.

[7] Y. Akinay, "The electromagnetic wave absorption properties of woven glass fiber composites filled with Sb 2 O 3 and SnO 2 nanoparticles doped mica pigments," no. July, pp. 8784–8794, 2022.

[8] U. Sorgucu, "Potential of Commercial Titanium in Electromagnetic Shielding for 5G Frequency Domain TT - 5G Frekans Bölgesi için Ticari Titanyumun Elektromanyetik Ekranlama Potansiyeli," Mühendislik Bilim. ve Araştırmaları Derg., vol. 6, no. 2, pp. 198–207, 2024.

[9] E. Delihasanlar and A.H. Yüzer, "The effect of conductive weft-knitted fabric structure on electromagnetic shielding at 1-12 GHz frequencies," J. Mater. Electron. Devices, vol. 5, no. 1, pp. 18–20, 2021.

[10] E. Erdem, "Hybrid rib fabric electromagnetic shielding measurement in X-band," Textile Research Journal, 2024.

[11] E. Delihasanlar and A.H. Yuzer, "Wearable Textile Fabric Based 3D Metamaterials Absorber in X-Band," Appl. Comput. Electromagn. Soc. J., vol. 35, no. 2, pp. 230–236, 2020.

[12] E. Erdem and A.H. Yuzer, "Textile-based 3D metamaterial absorber design for X-band application," Waves in Random and Complex Media, 2022.

[13] R. Abdulla, E. Delihasanlar, F. G. K. Abdulla, and A. H. Yuzer, "Electromagnetic shielding characterization of conductive knitted fabrics," Prog. Electromagn. Res. M, vol. 56, no. January, pp. 33–41, 2017.

[14] [14] E. Erdem, "Hybrid rib fabric electromagnetic shielding measurement in X-band," Text. Res. J., p. 00405175241288888, Oct. 2024.

[15] M. Nauman, R. Saleem, A.K. Rashid, and M.F. Shafique, "A miniaturized flexible frequency selective surface for X-band applications," IEEE Trans. Electromagn. Compat., vol. 58, no. 2, pp. 419–428, 2016.

[16] W. Huang, X. Liu, and E.W. Gill, Ocean wind and wave measurements using X-band marine radar: A comprehensive review, vol. 9, no. 12. 2017.

[17] A. Kumar and S. Singh, "Development of Coatings for Radar Absorbing Materials at X-band," IOP Conf. Ser. Mater. Sci. Eng., vol. 330, no. 1, 2018.

[18] A.A. Eltchaninov et al., "Review of studies of superradiative microwave generation in X band and Ka band relativistic BWOs (review)," IEEE Trans. Plasma Sci., vol. 32, no. 3 I, pp. 1093–1099, 2004.

[19] İ. İlhan, M. Esen, M. Karaaslan, and B.Y. Akyürek, "Investigation of EMI and UV-IR shielding properties of Kevlar and polyester/elastane nanocomposite fabrics coated by ECR and evaporation methods Investigation of EMI and UV-IR shielding properties of Kevlar and polyester/elastane nanocomposite fabrics," 2024.

[20] İ. Özkan, P.D. Baykal, and M. Karaaslan, "Investigation of electromagnetic shielding properties of metal composite tufted carpets," vol. 5000, 2020.

[21] S. Uzun et al., "Highly conductive and scalable Ti3C2Tx-coated fabrics for efficient electromagnetic interference shielding," Carbon N. Y., vol. 174, pp. 382–389, 2021.

[22] M. Tian, M. Du, L. Qu, S. Chen, S. Zhu, and G. Han, "Electromagnetic interference shielding cotton fabrics with high electrical conductivity and electrical heating behavior: Via layer-by-layer self-assembly route," RSC Adv., vol. 7, no. 68, pp. 42641–42652, 2017.

[23] H. Natarajan and P. Siddhan, "Weaving the Future: Exploring Electromagnetic Shielding Textiles," in Textile Materials for Good Health and Wellbeing: Design and Applications, S. Sundaramoorthy, S. Kubera Sampath Kumar, and M. V. Chavhan, Eds. Singapore: Springer Nature Singapore, 2024.

[24] E.- Elektronik and S. Yenİkaya, "Grafen tabanlı çift katmanlı yapının ekranlama etkinliği üzerine parametrik çalışma" Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi Pamukkale University Journal of Engineering Sciences vol. 29, no. 2, pp. 151–157, 2023.

[25] Z. Değirmenci and E. Çoruh, "Comparison of the performance and physical properties of plain, pique, double-pique and fleeced knitted fabrics," Tekst. ve Konfeksiyon, vol. 26, no. 2, pp. 159–165, 2016.

[26] E. Delihasanlar and A.H. Yuzer, "Simulation modelling and calculation of dielectric permittivity of Opuntia at 1.7–2.6 GHz," J. Microw. Power Electromagn. Energy, vol. 51, no. 2, pp. 150–158, 2017.

[27] V. Tunakova et al., "Hybrid knitted fabric for electromagnetic radiation shielding," J. Eng. Fiber. Fabr., vol. 15, 2020.