Fibers and Polymers 2020, Vol.21, No.10, 2380-2388
DOI 10.1007/s12221-020-3140-2

ISSN 1229-9197 (print version)
ISSN 1875-0052 (electronic version)

Shielding-benefit Evaluation of Electromagnetic Radiation and UV Radiation for Multifunctional Composite Polypropylene Woven Fabrics

Ting An Lin[1], Yu-Chun Chuang[2], Jan-Yi Lin[3], Mei-Chen Lin[1], Ching-Wen Lou[4,5,6,7,8]*, Keng Siang Sim[3], and Jia-Horng Lin[5,6,9,10,11]*

[1]*Department of Science and Technology, Graduate School of Medicine, Science and Technology, Shinshu University, Nagano Prefecture 390-8621, Japan*
[2]*Interdisciplinary Graduate School of Science and Technology, Shinshu University, Nagano Prefecture 390-8621, Japan*
[3]*Laboratory of Fiber Application and Manufacturing, Department of Fiber and Composite Materials, Feng Chia University, Taichung City 40724, Taiwan*
[4]*Innovation Platform of Intelligent and Energy-Saving Textiles, School of Textiles, Tiangong University, Tianjin 300387, China*
[5]*Fujian Key Laboratory of Novel Functional Textile Fibers and Materials, Minjiang University, Fuzhou 350108, China*
[6]*College of Textile and Clothing, Qingdao University, Shangdong 266071, China*
[7]*Department of Bioinformatics and Medical Engineering, Asia University, Taichung 41354, Taiwan*
[8]*Department of Medical Research, China Medical University Hospital, China Medical University, Taichung 40402, Taiwan*
[9]*School of Chinese Medicine, China Medical University, Taichung 40402, Taiwan*
[10]*Department of Fiber and Composite Materials, Feng Chia University, Taichung City 40724, Taiwan*
[11]*Tianjin and Ministry of Education Key Laboratory for Advanced Textile Composite Materials, Tiangong University, Tianjin 300387, China*

(Received November 30, 2018; Revised December 19, 2019; Accepted February 8, 2020)

Abstract: People have increasingly rising health consciousness in recent years and researchers are thus devoted themselves to develop multi-functional textile products. In this study, stainless steel (SS) filaments are used for electromagnetic shielding effectiveness (EMSE) while polypropylene (PP) filaments are used for ultraviolet resistance and good mechanical properties. Spinning and weaving continuous formation techniques are employed to produce wrapped yarns with SS and PP filaments, after which a weaving process is employed for the preparation of SS/PP woven fabrics. The woven fabrics are tested for EMSE and UV resistance, examining the effect of the lamination-layer numbers and lamination-layer angles. Test results show that the optimal EMSE and UV resistance occur when SS/PP woven fabrics are laminated with two layers at 90 °. Not only focus on the mechanical performance, the proposed woven fabrics with good EMSE, UV resistance, and a light weight, and are good candidate for a variety of application as required. The proposed UV resistance and EMSE woven fabrics significantly increase the additional values of traditional textiles.

Keywords: Electromagnetic shielding effectiveness (EMSE), High-strength polypropylene (PP) filament, Stainless steel (SS) filament, UV resistance, Protective textile products

Introduction

High-tech electrical products and equipment have been used in our daily lives massively in recent years, which inevitably causes numerous hidden harms, such as electromagnetic radiation. Electromagnetic radiation (*i.e.* electromagnetic wave) is composed of orthogonal electric field and magnetic field [1]. In the 2002 World Health Organization (WHO) report, it is not a new phenomenon that people have been exposed to excessive electromagnetic radiation [2]. Both Bergqvis*t et al.* (1997) and Stenberg *et al.* (2004) indicated that symptoms of electrical hypersensitivity patients, such as dizziness, memory loss, and neurological disturbances, which were ascribed to exposed to electric sources and VDT (video display terminal) work. The molecules of the human body are accelerated to create heat by the electromagnetic radiation. If the heat cannot be dissipated, it will jeopardize the organs [3]. Electromagnetic radiation gives rise to the mutation and tearing of chromosome, the unusual phenomenon of which hinders the regeneration of RNA and DNA and then causes abnormal chemical reaction that converts normal cells into cancer cells [4]. Moreover, electromagnetic radiation interferes with electrical equipment, causing machine to go haywire or be damaged [5]. Therefore, products with electromagnetic shielding effectiveness (EMSE) engage the academic and industrial fields [6-9]. Jagatheesan *et al.* proposed that EMSE could be attained via reflection, absorption, and multiple reflections. Electromagnetic waves that were not attenuated would penetrate the object [10]. As a result, many researchers studied about shield or attenuation of electromagnetic waves as well as relationship between materials intrinsic properties/ parameters and EMSE.

In general, metal, intrinsic conductive polymer [11], electroless-coating fabrics [12-16], carbon fiber, and carbon

*Corresponding author: cwlou@asia.edu.tw
*Corresponding author: jhlin@fcu.edu.tw

nanotubes are ideal shielding materials against electromagnetic waves. In particular, metallic fibers that are fabricated into fabrics have good EMSE but they easily wear off the machine and give the users rigid texture. Hu *et al.* fabricated conductive textiles using metallic coating [17]. However, the coating layer had a low adsorption and easily fell off, let alone the required toxic electroless plating solution that could harm the environment [18-21]. Palamutcu developed an electromagnetic shielding efficiency measurement set to measure the conductive knits and woven fabrics. They compared the coating effect between cotton/copper and cotton/copper/silver wrapped yarns, determining the optimal wrapped yarns which did not have the flaws of all-metal fabrics but maintained good EMSE [22]. Ozdemir and Ozkurt conducted a free space measurement at horizontal polarization of the antenna, evaluating the EMSE of woven fabrics that were composed of stainless steel core yarns and different weft densities. When the weft yarns were parallel to antenna polarization, the woven fabrics exhibited optimal EMSE. When the weft yarns were perpendicular to antenna polarization, the EMSE was proportional to the steel core yarns density [23].

Duran and Kadoglu combined silver fiber-based core yarns and blended yarns to form woven fabrics. The test results showed that the EMSE was dependent on the parameters of yarns and fabrics, such as electrical resistivity, yarn type and frequency [24]. Ozdemir *et al.* used stainless steel yarns as conductive yarns to form twill and sateen woven fabrics. The woven fabrics were evaluated using the free space measurement technique with different antenna polarizations. The test results showed that both fabrics had good EMSE (-40 dB) at medium and high frequencies [25]. Safarova *et al*. combined polypropylene fibers and stain steel fibers to form hybrid yarns, which were fabricated into fabrics. The fabrics were evaluated for EMSE in order to examine the influences of content of metallic fiber, size of apertures, cover factor, and aperture area. The test results showed that the EMSE was proportional to the content of metallic fiber. Moreover, the proposed numerical model could be used to predict the EMSE of the fabrics based on the size of apertures, thickness of sample, and volume of resistivity [26]. Lou *et al*. investigated the influence of the number of lamination layers and lamination angles on the EMSE of stainless steel/polyester and copper/polyester woven fabrics. It was found that variation in lamination angles had a greater influence than the number of lamination layers [27]. Lin *et al*. proposed using stainless steel, copper, or nickel-coated copper as the metallic material to make metal/polyester composite plain materials. The EMSE of the plain materials was evaluated. The 3-layered plain materials that were laminated at 90 ^{o} had the optimal EMSE of above -45 dB at frequencies of 2000-3000 MHz [28]. Electromagnetic waves adversely affect people's health, and ultraviolet radiation does likewise. A long-term exposure to UV radiation may result in acute and chronic negative interference with the skin, eyes, and immune system. In light of wave length, UV radiation can be divided into ultraviolet A (UVA), ultraviolet B (UVB), and ultraviolet C (UVC), ranging 100-400 nm [29]. Therefore, people express considerable concern about UV resistance and have demands for UV cut functional textiles.

In this study, due to having least oxidization and low cost, stainless steel filaments are used as the major metallic material in order to block electromagnetic waves. Next, the wrapped yarns are made for UV resistance as follows. 150 D polypropylene (PP) filaments with high strength and good UV resistance are used as the sheath material, and stainless steel (SS) filaments with diameters of 0.05 mm and 0.08 mm are used as the core material. The resulted SS/PP wrapped yarns are used as the weft yarns, and 500 D PET yarns as the warp yarns are made into SS/PP woven fabrics. The mechanical properties, EMSE, and UV resistance of the woven fabrics are tested. It is expected that the multifunctional composite woven fabrics with suitable properties can be applied as industrial or indoor/interior radiation-shielded fabrics.

Experimental

Materials

Stainless steel (SS) filaments (Yuen Neng, Taiwan) have diameters of 0.05 mm and 0.08 mm SS filaments are used for electromagnetic interference shielding effectiveness. Polypropylene (PP) filaments have UV-blocking effect and a fineness of 150 D. Woven fabrics (Yi Jinn Industrial, Taiwan) are composed of 500 D polyester (PET) filaments and SS/PP wrapped yarns as warp yarns and weft yarns, respectively. Table 1 displays the basic properties of raw materials.

Manufacturing Process

Preparation of SS/PP Wrapped Yarns

The wrapping process of SS/PP wrapped yarns is

Table 1. Characteristics of raw materials

Material	Diameter (mm)	Fineness (D)	Stress (cN)	Elongation (%)	Strength (cN/dtex)
Stainless steel filament	0.05	-	144.29	18.11	1.44
	0.08	-	336.18	12.39	3.36
PP filament	-	150	2234.09	24.52	13.40

conducted using an automatic covering machine (DH CR-20, Dah Heer, Taiwan) as Figure 1. PP filaments (150 D) are coiled surrounding two green tubes. The tubes are set in the

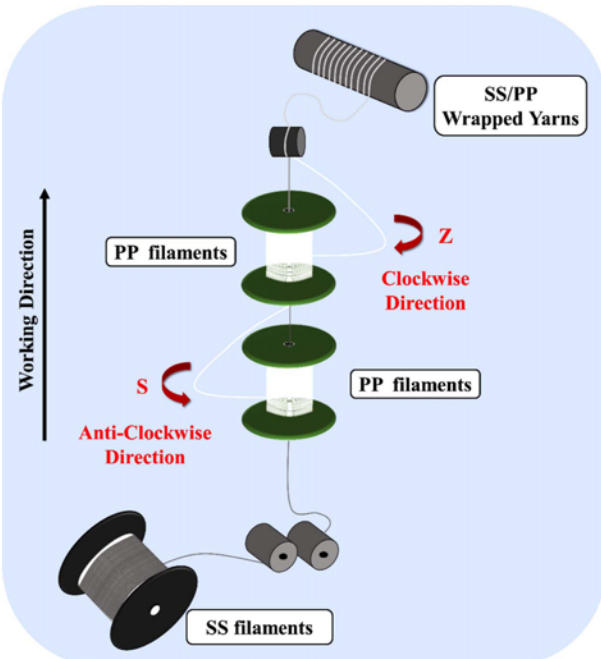

Figure 1. Wrapping process of SS/PP wrapped yarns.

upper and lower winding place and operate clockwise and anti-clockwise, separately. SS filaments are in the lowest position and used as the core. The sheath and core are fed from the lower part and combined with twist counts being 7 and 9 turns/cm. Single-ply and double-ply wrapped yarns are produced accordingly and collected on the highest position.

Preparation of SS/PP Woven Fabrics

A rapier loom machine (KINGSTON280S, King Kon Iron Works, Ltd., Taiwan) is used to fabricate SS/PP wrapped yarns (*i.e.* the weft yarns) and 500 D PET filaments (*i.e.* the warp yarns) into SS/PP woven fabrics. The woven fabrics are then laminated with different lamination-layer numbers and lamination-layer angles in electromagnetic shielding effectiveness and ultraviolet radiation shielding tests. Figure 2 shows the schematic diagram and arrangements of SS/PP woven fabrics.

Tests

Surface Resistivity

Surface resistivity of woven fabrics is measured using a metal detector and a digital multimeter (M3500A, PICOTEST Co., Ltd., Taiwan) as specified in JIS L1094. A sample is mounted on the platform while its thickness and size are the required input to the software. A total of five samples are tested and the average surface resistivity is recorded.

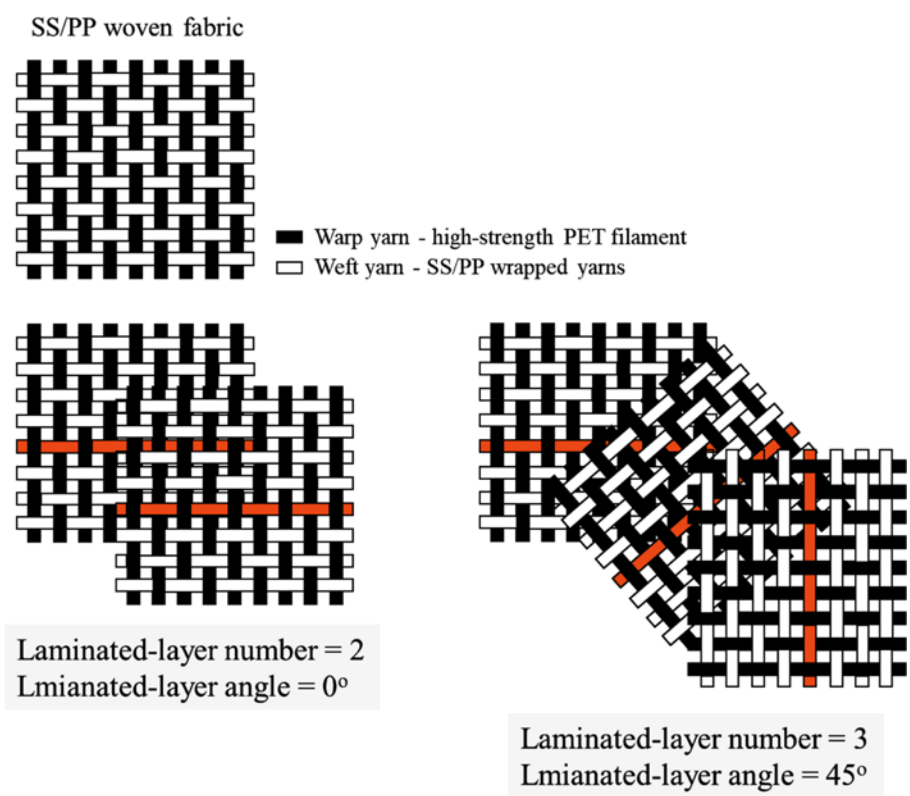

Figure 2. Schematic diagram of SS/ PP woven fabric.

Table 2. Test parameters of SS/PP woven fabric

Lamination-layer angles (rotation angle)	Lamination-layer numbers		
	1	2	3
0°	0°	0°/0°	0°/0°/0°
45°	-	0°/45°	0°/45°/90°
90°	-	0°/90°	0°/90°/180°

EMSE

A shielding effectiveness test sample holder (EM-2107A, E-Instrument Tech Ltd., Taiwan) and a network analyzer are used to measure the EMSE of samples as specified in ASTM D 4935-10. The scan frequency is between 300 kHz and 3GHz. EMSE is computed using equation (1) and presented in decibel (dB). Table 2 contains the arrangements during the test.

$$SE(dB) = R + A + B \tag{1}$$

where R is reflection loss, A is absorption loss, and B is multi-reflection loss.

Tensile Properties

The maximum tensile stress and elongation of SS/PP woven fabrics are measured using a computer universal testing machine (Hung Ta Instrument, Taiwan) as specified in CNS 12915 standard. Tensile properties along the weft and warp direction of woven fabrics are measured.

UV Resistance Measurement

A self-assembled UV intensity meter is used to measure the UV resistance of woven fabrics as specified in GB-T 17032. Sample size is 10×10 cm. The tester is heated for thirty minutes beforehand. The radiation intensity of the UV lamp is measured. A sample is placed in the meter and kept 15 cm apart from the lamp at a peak wave of 297 nm. The UV detector beneath sample is used to detect sample's UV absorptive capacity. The detector has a detection range of 290-320 nm UV. Three samples for each specification are tested. The test period is ten minutes.

Sample Code and Basic Physical Properties of SS/PP Wrapped Yarns and Woven Fabrics

The wrapped yarns are denoted based on the diameter of SS filament (*i.e.* 0.05 and 0.08 mm), twist counts (*i.e.* 7 and 9 turns/ cm), and number of ply (*i.e.* single (S)/double (D) ply). For example, 005-7-S means the single ply wrapped yarns are composed of 0.05 mm SS filament as core and sheath material with a twist counts of 7 turns/ cm. Woven fabrics are denoted likewise and has W as abbreviation of woven fabrics. For example, 005-7-S-W is SS/PP woven fabric that is composed of 005-7-S wrapped yarns as the weft yarns. Tables 3 and 4 show the physical properties of SS/PP wrapped yarns and woven fabrics, respectively, while Figure 3 shows their stereomicroscopic images.

Table 3. Physical properties of SS/PP wrapped yarns

Sample code	Stress (cN)	Elongation (%)	Denier (D)	Strength (cN/dtex)	Sheath/core ratio (%)
005-7-S	1553.91	18.73	478	2.92	69/31
005-7-D	3749.31	31.71	842	4.00	82/18
005-9-S	2098.75	30.43	515	3.67	65/35
005-9-D	2238.34	29.57	995	2.03	83/17
008-7-S	2498.21	31.06	710	3.16	52/48
008-7-D	3330.69	30.53	1148	2.61	70/30
008-9-S	2074.15	27.21	729	2.56	50/50
008-9-D	2071.13	29.59	1251	1.49	72/28

*S-single ply, D-double ply, 7=7 turns/cm, 9=9 turns/cm.

Table 4. Physical properties of SS/ PP woven fabrics

Sample codes	Warp yarn	Weft yarn	Weight (g/m^2)	Thickness (mm)	Cover factor
005-7-S-W	500 D PET	005-7-S	1432	0.58	16.92
005-7-D-W	500 D PET	005-7-D	1746	0.78	20.25
005-9-S-W	500 D PET	005-9-S	1457	0.63	16.87
005-9-D-W	500 D PET	005-9-D	1733	0.79	21.43
008-7-S-W	500 D PET	008-7-S	1771	0.56	19.15
008-7-D-W	500 D PET	008-7-D	2070	0.72	22.52
008-9-S-W	500 D PET	008-9-S	1807	0.59	19.30
008-9-D-W	500 D PET	008-9-D	2074	0.76	24.39

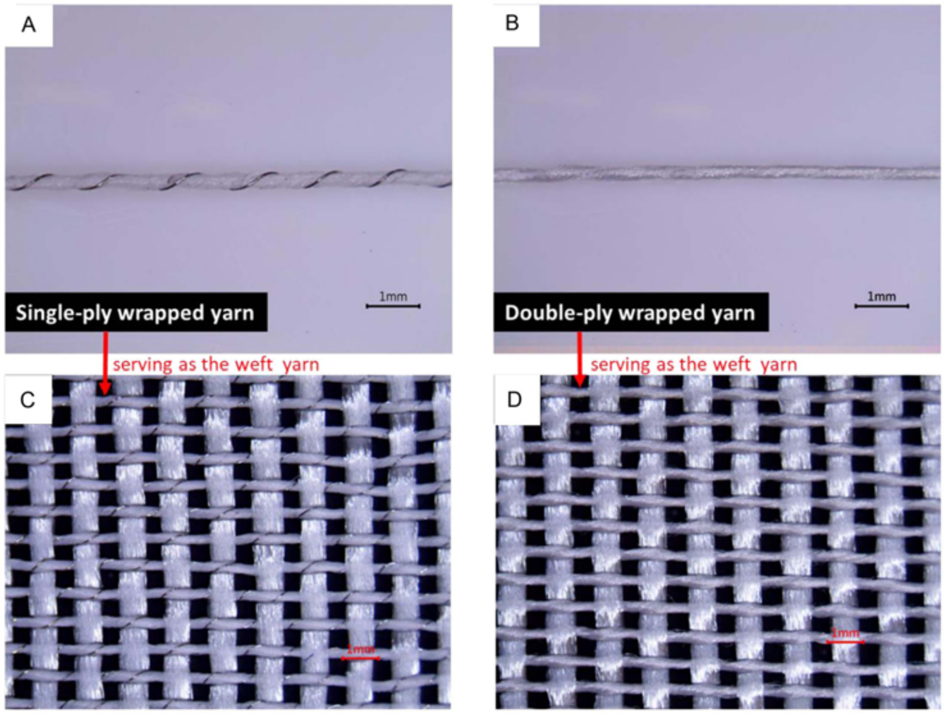

Figure 3. Images of (A) single-ply wrapped yarns, (B) double-ply wrapped yarns, and (C) woven fabric with single-ply wrapped yarns serving as the weft yarns (D) woven fabric with double-ply wrapped yarns serving as the weft yarns.

Results and Discussion

Surface Resistivity of SS/PP Woven Fabric

Figure 4 shows the surface resistivity of SS/PP woven fabrics that are composed of wrapped yarns consisting of 0.05 mm and 0.08 mm SS filaments. It is clearly indicated that the woven fabrics having single-ply wrapped yarns as the weft yarns (005-7-S-W, 005-9-S-W, 008-7-S-W, and 008-9-S-W) have lower surface resistivity and thus greater electrical conductivity. Conversely, the woven fabrics having double-ply wrapped yarns as the weft yarns (005-7-D-W, 005-9-D-W, 008-7-D-W, and 008-9-D-W) have higher surface resistivity and thus lower electrical conductivity. The is because that the conductive stainless steel filament is appeared on the surface of wrapped yarns when under single-ply manufacturing process. Hence, 005-7-S-W and 005-9-S-W have higher conductivity, which are 1.59E+06 and 1.18E+06. In addition, the woven fabrics composed of double-ply wrapped yarns have relatively higher surface resistivity. SS core of double-ply wrapped yarns is enwrapped completely, which makes it difficult for metal detector to contact the SS core, which leads to comparatively higher surface resistivity.

Effects of Lamination-layer Angles and Lamination-layer Numbers on EMSE

In the EMSE measurement, the lamination-layer angles (0°, 45°, and 90°) and lamination-layer numbers (1, 2, and

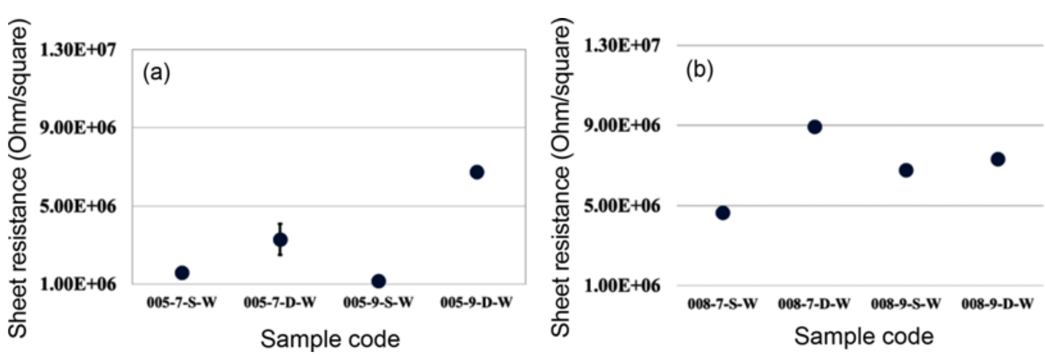

Figure 4. Surface resistivity of SS/PP woven fabrics composed of SS filaments of a diameter of (a) 0.05 mm and (b) 0.08 mm.

3 layers) are factors to the EMSE of SS/PP woven fabrics. The following discussions based on a specified lamination-layer angles and diverse lamination-layer numbers.

Lamination-layer Angles of 0 °

Figure 5 shows that increasing the lamination-layer numbers, the EMSE of woven fabrics slightly increases and is between -5 dB and -20 dB at frequency band between 1.5 GHz and 3.0 GHz. It is known that the electric field and magnetic field are perpendicular to each other during the moving process, and thus when the woven fabric with a 0 ° lamination-layer angles can only shield electromagnetic radiations along a single direction. This is because when woven fabrics are aligned at the same lamination-layer angle, the shielding network is not completely formed. As a result, regardless of the lamination-layer numbers, the woven fabrics at a 0 ° lamination angle are unable to shield incident electromagnetic waves effectively, which the electromagnetic shielding effectiveness are all over -20 dB.

Lamination-layer Angles of 45 °

Figure 5 shows that when the woven fabrics are laminated at 0 °, there is no significant difference in EMSE regardless of whether the lamination-layer numbers being 1, 2, or 3 layers. By contrast, Figure 6 shows that a 45 ° lamination angle contributes a significant rise in EMSE of woven fabrics in full band. The EMSE is between -15 dB and -45 dB at frequency of 1.5 GHz-3.0 GHz, shielding 99.9999 % of electromagnetic waves. In particular, 008-7-D-W exhibits the optimal EMSE of -51 dB at a frequency of 2.2 GHz, shielding 99.9999 % of electromagnetic waves. Because a 45 ° lamination-layer angle generates a dense conductive network, there are more loops per unit area. Similarly, a greater lamination-layer number also increases the fabric density and metallic content, enabling the woven fabric to shield electromagnetic waves effectively. However, EMSE of woven fabrics at 45 ° decreases as a result of shielding high-frequency electromagnetic waves. This result is ascribed to the fact that the frequency (f) is inversely proportional to the wavelength (λ). A high frequency means a low wavelength equivalently, which allows electromagnetic waves to penetrate the voids in woven fabrics without being attenuated by reflection, absorption, and multiple reflections.

Lamination-layer Angles of 90 °

Lamination-layer angles of 0 ° and 45 ° provide the woven fabrics with EMSE of -5 dB~-15 dB and -15 dB~-45 dB (Figures 5 and 6). Figure 7 shows a lamination angle of 90 ° provides the woven fabrics with EMSE of -20 dB~-60 dB between 1.5 GHz and 3.0 GHz, which reaches the domestic and industrial standards. In particular, 008-7-D-W at a 90 ° lamination angle has EMSE of -55 dB at frequency of 2.0 GHz, shielding 99.999 % of electromagnetic waves. Due to the fact that electromagnetic waves are propagated perpendicularly, a lamination-layer angle of 90 ° provides woven fabrics with high EMSE. Moreover, with a specified lamination-layer angle of 90 °, increasing the lamination-layer number simultaneously increases the metallic content per unit area, which results in a denser conductive network and a larger loop area that shield electromagnetic interference. However, regardless of whether it is single-ply or double-ply wrapped yarn, the EMSE of woven fabrics does not fluctuate distinctively. Noticeably, the diameter of SS filaments has a much greater influence on the EMSE. High thickness of metallic wire means more metallic content and woven fabrics containing 0.08 mm SS filaments thus have

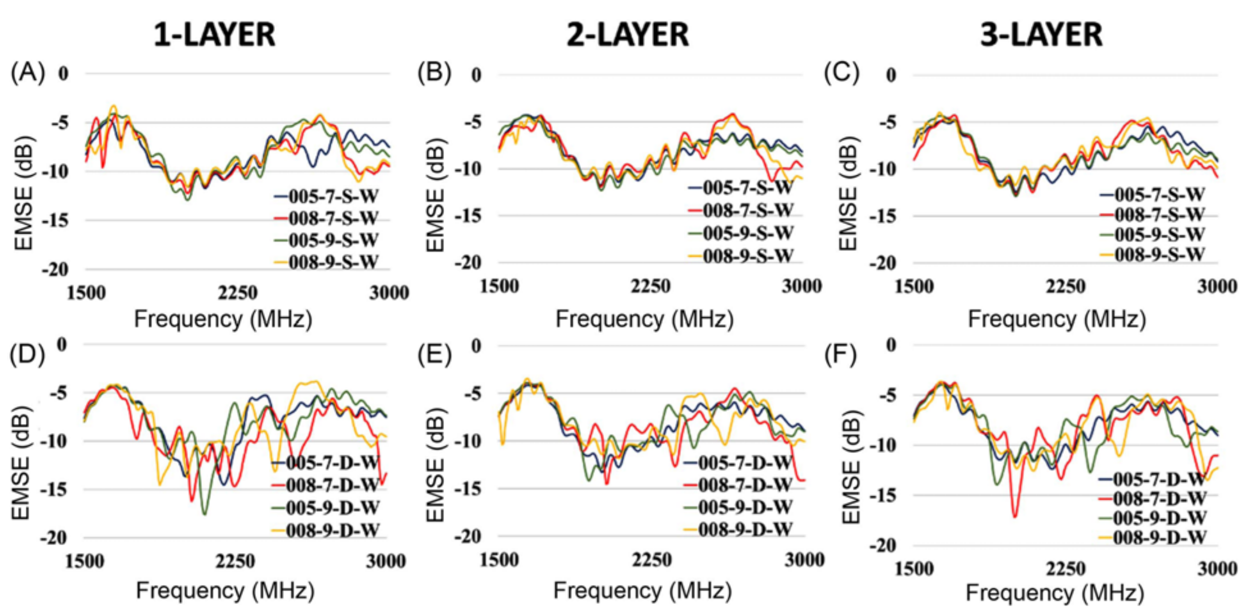

Figure 5. EMSE of SS/PP woven fabrics that are made of (A-C) single-ply and (D-F) double-ply SS/PP wrapped yarns as the weft yarns with various lamination-layer numbers 1 to 3, respectively. The lamination angle is 0 °.

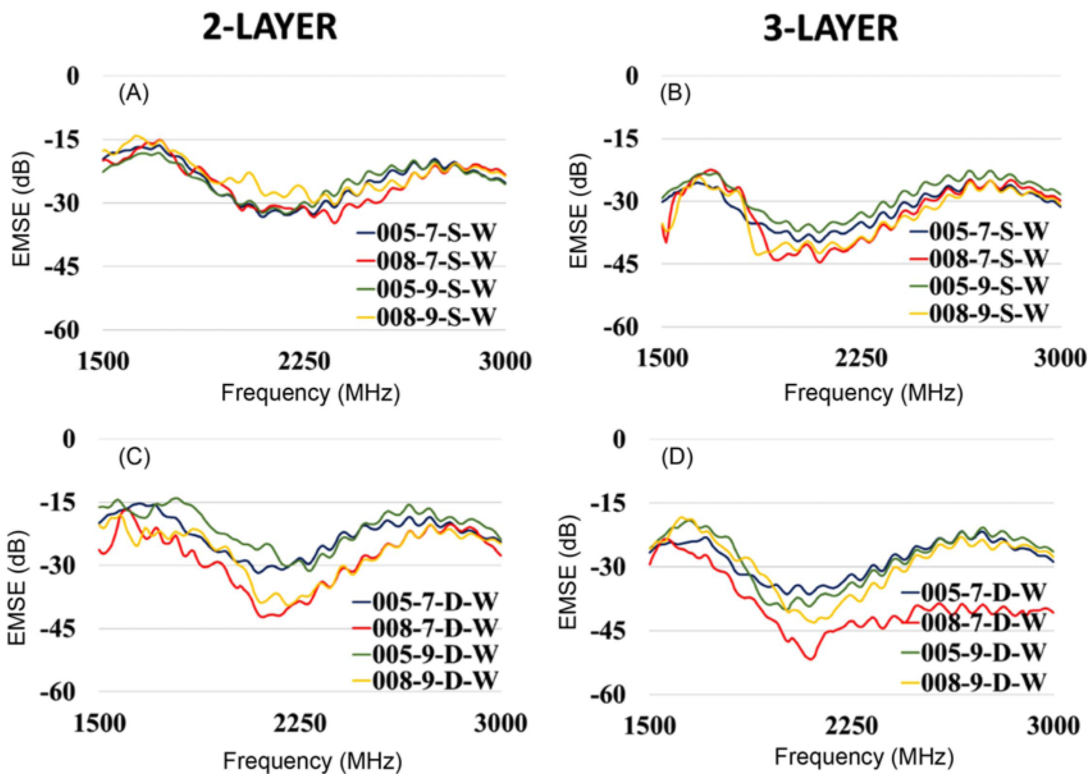

Figure 6. EMSE of SS/PP woven fabrics that are made of (A, B) single-ply and (C, D) double-ply SS/PP wrapped yarns as the weft yarns with various lamination-layer numbers 2 and 3, respectively. The lamination angle is 45 °.

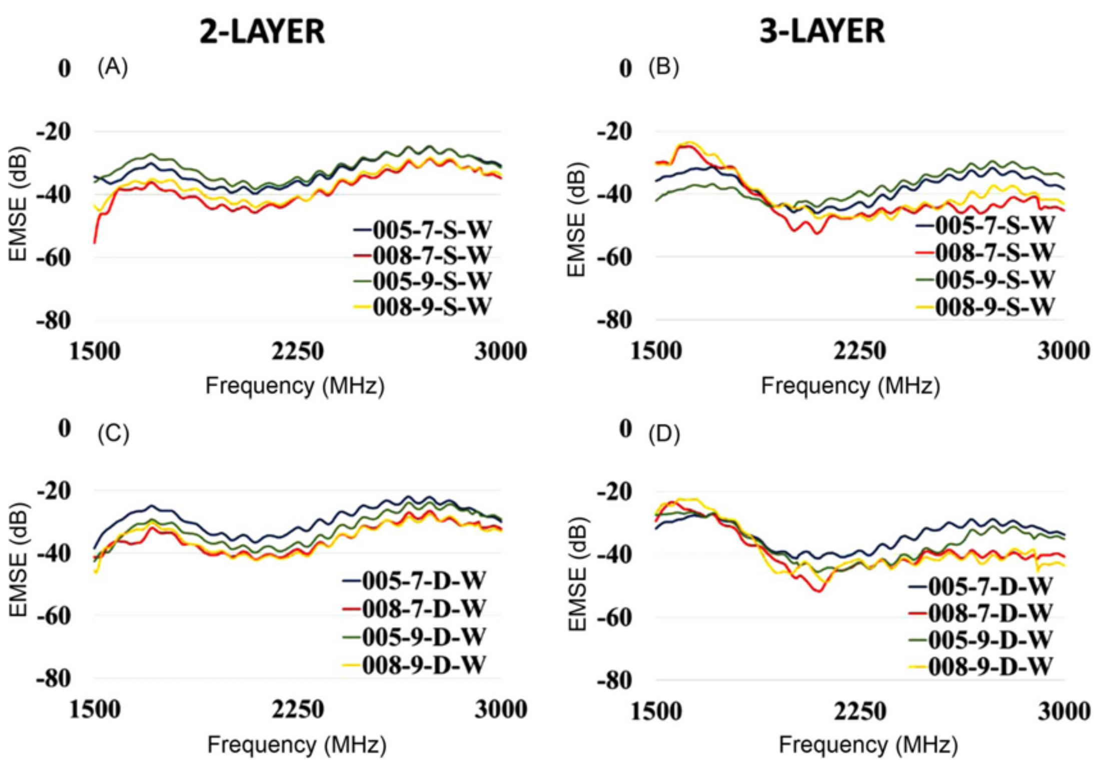

Figure 7. EMSE of SS/PP woven fabrics that are made of (A, B) single-ply and (C, D) double-ply SS/PP wrapped yarns as the weft yarns with various lamination-layer numbers 2 and 3, respectively. The lamination angle is 90 °.

relatively higher EMSE.

Maximum Tensile Stress and Maximum Elongation of SS/PP Woven Fabric

Figure 8(A and C) shows the contrary results as woven fabrics composed of single-ply wrapped yarns have greater tensile stress along the warp direction but woven fabrics composed of double-ply wrapped yarns have greater tensile stress along the weft direction. In Figure 8(A), the strength of weft yarn (*i.e.* SS/PP wrapped yarns) is lower than that of the warp yarns (*i.e.* 500 D PET yarns) that is 7.03 cN/dtex. Besides, the weft yarns are finer than the warp yarns, and thus the tensile stress along the warp direction is higher. Figure 8(C) shows the tensile stress of SS/PP woven fabrics along the weft direction is higher than the warp directions, which is against to the results of Figure 8(A). This is because double-ply wrapped yarns can bear the tensile stress well with a better structure. As for Figure 8(B and D), the weft yarns of the woven fabrics are wrapped yarns and the warp yarns are 500 D PET yarns. Hence, the maximum tensile elongation along the weft direction is higher than the warp direction because the weft yarns are resilient while the warp yarns are not.

Effects of Lamination-layer Angle and Lamination-layer Number on UV Transmittance

Figure 9 shows that for 1-layered woven fabrics, those composed of double-ply SS/PP wrapped yarns have lower

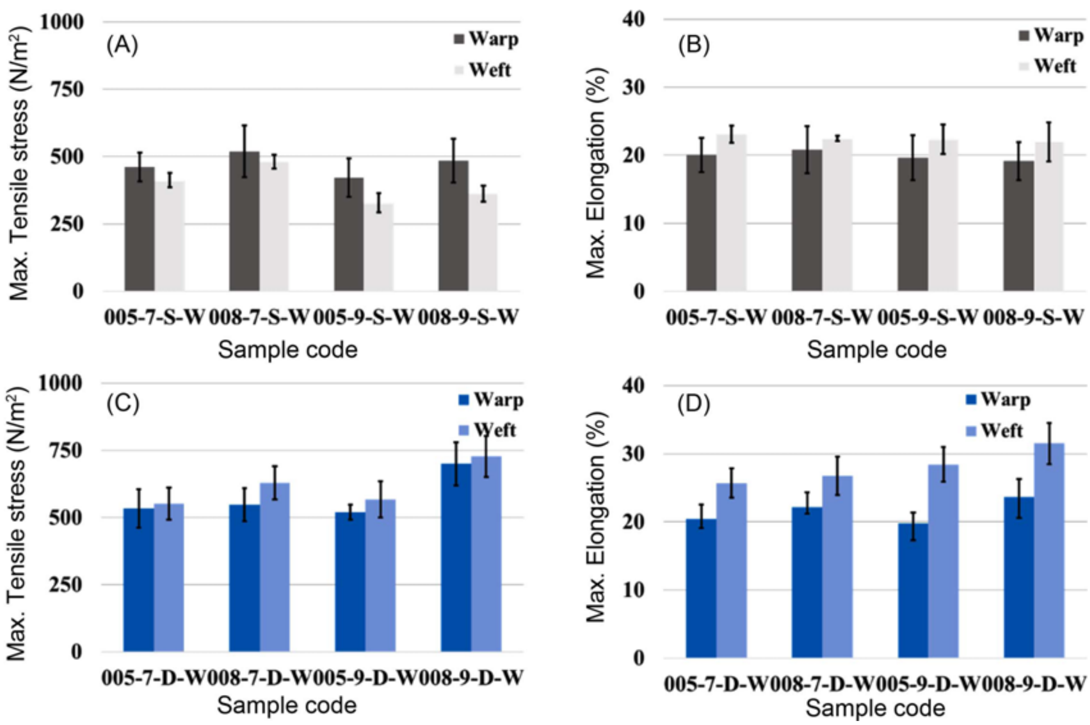

Figure 8. Tensile stress and stress along the warp and weft directions of SS/PP woven fabrics that are composed of (A, B) single-ply and (C, D) double-ply SS/PP wrapped yarns as the weft yarns.

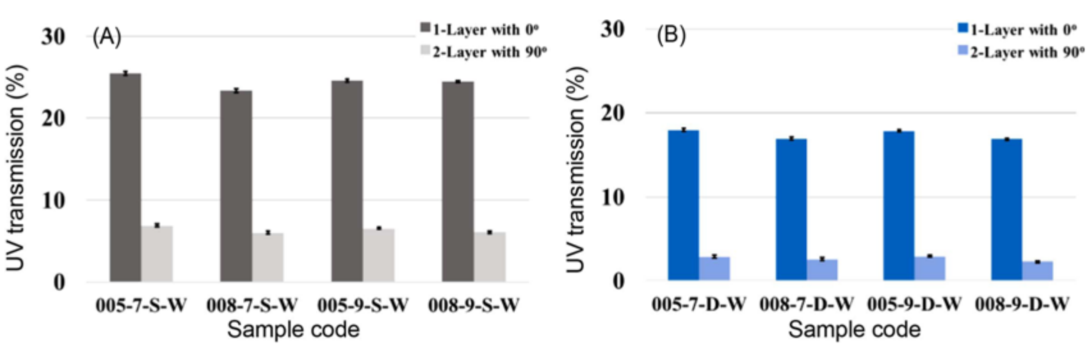

Figure 9. UV transmission of SS/PP woven fabrics that are composed of (A) single-ply and (B) double-ply SS/PP wrapped yarns as the weft yarns. The lamination-layer numbers are 1 and 2, and the laminated-layer angles are 0 ° and 90 °.

UV transmission than those composed of single-ply SS/PP wrapped yarns. A low UV transmission indicates a high UV resistance. Moreover, for 2-layered woven fabrics, regardless of the constituent wrapped yarns being single- or double-ply, the woven fabrics that are laminated at 90 ° have a lower UV transmission than those that are laminated at 0 °. Compared to 1-layered woven fabrics, 2-layered woven fabrics have greater UV resistance, a UV transmission lower than 10 %. It is surmised that the woven fabrics have 500 D PET filaments as the warp yarns that are not UV resistant. A lamination-layer angle of 90 ° renders 2-layered woven fabrics with SS/PP wrapped yarns both along the warp and weft directions. Simultaneously, 2-layered woven fabrics have a higher fabric thickness and smaller porosity, which blocks the penetration of UV radiation and results in higher UV resistance.

Conclusion

This study proposes UV cut and EMSE woven fabrics that are composed of SS/PP wrapped yarns consisting of 150 D high strength UV resistant PP filaments as well as 0.05 and 0.08mm SS filaments. The test results show that 005-7-S-W and 005-9-S-W have optimal electric conductivity of 1.59E+06 and 1.18E+06. Woven fabrics composed of single-ply wrapped yarns have greater tensile stress along the warp direction. By contrast, all of the woven fabrics exhibit higher tensile elongation along the weft direction. When laminated at 90 °, woven fabrics exhibit an optimal EMSE and optimal UV resistance. In addition to good EMSE and ultraviolet resistance, SS/PP woven fabrics have a light weight and can be adjusted to form textile products according to the requirement of user end. It is expected that the multifunctional composite polypropylene woven fabrics have diverse applications, such as industrial UV-radiated shielding fabrics or interior electromagnetic shielding materials.

Acknowledgements

The authors would especially like to thank Ministry of Science and Technology of Taiwan, for financially supporting this research under Contract MOST 106-2622-E-468-05-CC3, MOST 107-2622-E-035-011-CC3 and MOST 107-2632-E-035-001-.

References

1. R. Erdem, *Bull. Mat. Sci.*, **39**, 963 (2016).
2. W. H. Organization, "Establishing a Dialogue on Risks from Electromagnetic Fields", Geneva, Switzerland, 2002.
3. W. H. Organization, "Ionizing Radiation, Health Effects and Protective Measures", 2016.
4. K. Lai, R. J. Sun, M. Y. Chen, H. Wu, and A. X. Zha, *Text. Res. J.*, **77**, 242 (2007).
5. C. I. Su and J. T. Chern, *Text. Res. J.*, **74**, 51 (2004).
6. L. M. Green, A. B. Miller, P. J. Villeneuve, D. A. Agnew, M. L. Greenberg, J. H. Li, and K. E. Donnelly, *Int. J. Cancer*, **82**, 161 (1999).
7. D. Wartenberg, *Bioelectromagnetics*, *Suppl.*, **5**, 586 (2001).
8. Energy Policy Act, PL 102-486, Section 2118, USA, 1992.
9. S. Ma, IEEE Potentials, **12**, 34 (1993).
10. K. Jagatheesan, A. Ramasamy, A. Das, and A. Basu, *Indian J. Fibre Text. Tes.*, **39**, 329 (2014).
11. S. Brzezinski, T. Rybicki, I. Karbownik, G. Malinowska, E. Rybicki, L. Szugajew, M. Lao, and K. Sledzinska, *Fibres Text. East. Eur.*, **17**, 66 (2009).
12. S. Q. Jiang, E. Newton, C. W. M. Yuen, and C. W. Kan, *Text. Res. J.*, **76**, 57 (2006).
13. Y. X. Lu and L. L. Xue, *Compos. Sci. Technol.*, **72**, 828 (2012).
14. Y. X. Lu, Q. Liang, and W. L. Li, *Mater. Chem. Phys.*, **140**, 553 (2013).
15. H. Zhao, Q. Liang, and Y. X. Lu, *Fiber. Polym.*, **16**, 593 (2015).
16. H. Zhao, L. Hou, and Y. X. Lu, *Chem. Eng. J.*, **297**, 170 (2016).
17. J. Hu, G. Li, J. Shi, X. Yang, and X. Ding, *Text. Res. J.*, **87**, 902 (2016).
18. A. Y., V. AR, "Advances in Agronomy – Environmental Chemistry of Silver in Soils: Current and Historic Perspective", Amsterdam, The Netherlands, 2012.
19. D. Barcelo, "Comprehensive Analytical Chemistry – Engineered Nanoparticles in Textiles and Textile Wastewaters", Elsevier, Amsterdam, The Netherlands, 2012.
20. R. H. Guo and S. Q. Jiang, "Surface Modification of Textiles Modification of Textile Surfaces Using Electro Less Deposition", Woodhead Publishing Limited, 2009.
21. R. Perumalraj and B. S. Dasaradan, *Indian J. Fibre Text. Tes.*, **36**, 35 (2011).
22. S. Palamutcu, A. Ozek, C. Karpuz, and N. Dag, *Tekstil Ve Konfeksiyon*, **20**, 199 (2010).
23. H. Ozdemir and A. Ozkurt, *Tekstil Ve Konfeksiyon*, **23**, 124 (2013).
24. D. Duran and H. Kadoglu, *Text. Res. J.*, **85**, 1009 (2015).
25. H. Ozdemir, S. S. Ugurlu, and A. Ozkurt, *J. Ind. Text.*, **45**, 416 (2015).
26. V. Safarova, M. Tunak, and J. Militky, *Text. Res. J.*, **85**, 673 (2015).
27. C. W. Lou, T. A. Lin, A. P. Chen, and J. H. Lin, *J. Ind. Text.*, **46**, 214 (2016).
28. J. H. Lin, T. A. Lin, T. R. Lin, J. C. Jhang, and C. W. Lou, *J. Ind. Text.*, **49**, 365 (2018).
29. Intersun; The Global UV Project, WHO (www.who.int), 2003.