Manufacturing Techniques and Electrical Properties of conductive Fabrics with Recycle Polypropylene Nonwoven Selvage

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Abstract In this research, an original rotor twister machine, with a speed of 8000 rpm, spun complex-ply yarns from recycled polypropylene nonwoven selvage (PPNS) and various metal wires. The core yarn was pieces of 30 g/m^2 recycled PPNS and the wrap yarns were 80 μm stainless steel wires. Furthermore, 80 μm stainless steel wires and 80 μm copper wires, parallel to the core yarns, reinforced the complex-ply yarns. Yarns were manufactured with wrap numbers of 0.5, 1.5, 2.5, 3.5, and 4.5 turns/cm. Complex fabrics were woven with the complex-ply yarns as the weft yarns and PVC-coated PET filaments as the warp yarns. These fabrics were evaluated for surface resistivity and electromagnetic shielding effectiveness (EMSE). The presence of copper reinforcement wires was found to lower the surface resistivity of the fabrics. The lowest surface resistivity was recorded for a fabric woven from yarns with a wrap number of 4.5 turns/cm; that surface resistivity was 28.7 Ω/sq. EMSE measurements showed that fabrics with varied lamination angles provided good electromagnetic shielding. The optimum EMSE measured in this research was 56.1 dB on incident frequency as 2.36 GHz, for a fabric with 0°/90°/0°/90°/0°/90° lamination angles.

Key words recycled polypropylene nonwoven selvage (PPNS), stainless steel wires, copper wires, rotor twister machine, electromagnetic shielding effectiveness (EMSE)

Introduction

Because polypropylene can replace materials such as glass, metals, and plastics, nonwoven polypropylene is increasingly used for insulation, geotextiles, filters, medical textiles, automotive interiors, and so on [1]. One third of all fibrous textile products are nonwoven [2]. In the USA, in 1992, consumption of nonwoven polypropylene surpassed consumption of nonwoven polyester fibers for the first time [3]. Textile production lines consume fresh polypropylene as raw material and produce as a by-product, but 3 to 5 % of that raw material becomes polypropylene selvage. Nonwoven selvage that has been thermally pressed or bonded cannot be used for conventional production [4]; it is usually burnt or used as stuffing. The sheer volume of nonwoven selvage demands a more effective means of disposal; this research promotes a means of recycling economically wasteful polypropylene nonwoven selvage (PPNS) into a valuable raw material.

Many of the necessities and conveniences of modern life, such as personal computers, cellular phones, and domestic electronics, generate static electricity and electromagnetic interference (EMI). EMI damages electronic components, interferes with signals, and causes other problems. In recent years, medical research has investigated the role of EMI in cancer, leukemia, and other diseases. Medical science has confirmed that electromagnetic fields influence human nervous systems, cardiovascular systems, and body temperatures [5-11].

The aim of this research was to make PPNS into fabrics with useful electromagnetic shielding effectiveness (EMSE). PPNS and metal wires were processed into complex-ply yarns, using a rotor twister machine. The selected materials could be seen from pre-existing literature [12-19]. Then the complex-ply yarns were woven as weft yarns on a loom that used PVC-coated PET filaments as warp yarns. The final products can be used to protect the human body or electronic products from electromagnetic waves and static electricity.

Experimental

Materials

Cheng-Yu Enterprise Company provided 30 mm-wide pieces of thermal-bonded nonwoven polypropylene selvage with an area mass of 30 g/m^2, as shown in Figure 1. King Metal Fiber Technology Company provided 80 μm stainless steel wires and Floodlit Enterprise Company provided 80 μm copper wires.

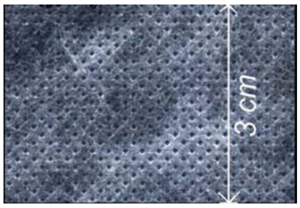


Figure 1 PPNS selvage with a width of 3 cm.

The manufacturing technique of recycled PPNS/M complex-ply yarns

Figure 2 shows the configuration of the rotor twister machine invented by the author, Dr. Lin. The stainless steel wires (B) were bent by the rotor twister (C) which was moved by a motor-driven tangent belt (D). While the rotor twister (C) was in motion, the winding roller (F) drew recycled PPNS, copper wires, and stainless steel wires through the thread eye (A) to form the complex-ply yarns yarn (G). The bearing (E) fixed the rotor twister. The wrap numbers of the complex-ply yarns depended on both the speed of the rotor twister and the speed of the winding roller. In this research, the speed of the rotor twister was held constant at 8000 rpm and the speed of the winding roller was varied to control each yarn's wrap number.

The wrap number of any yarn was determined by

$$N = \frac{R}{T \times D \times \pi} \qquad (1)$$

where T was the speed of the winding roller (rpm), R was the speed of the rotor twister (rpm), N was the wrap number of the complex-ply yarn, and D was the diameter of the winding roller (cm).

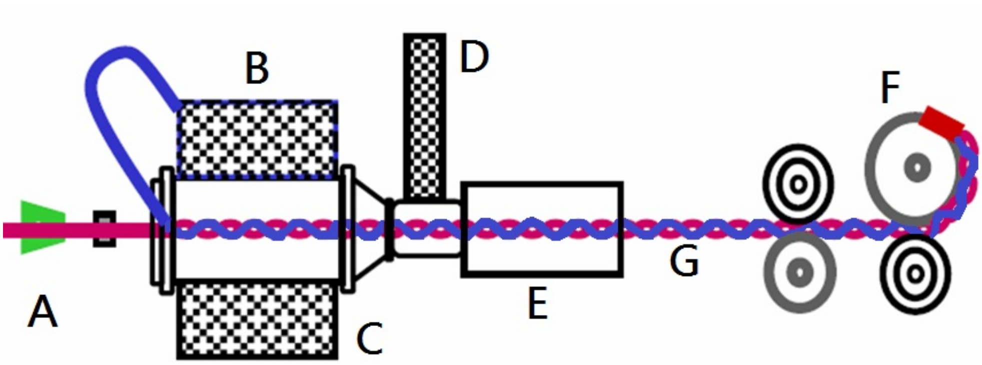


Figure 2 The configuration of the rotor twister [20].

All yarns without any core reinforcement were denoted type A-X, where X was the wrap number. Similarly, all yarns with only steel reinforcement wires were denoted type B-X, and all yarns with both steel and copper reinforcements were denoted type C-X.

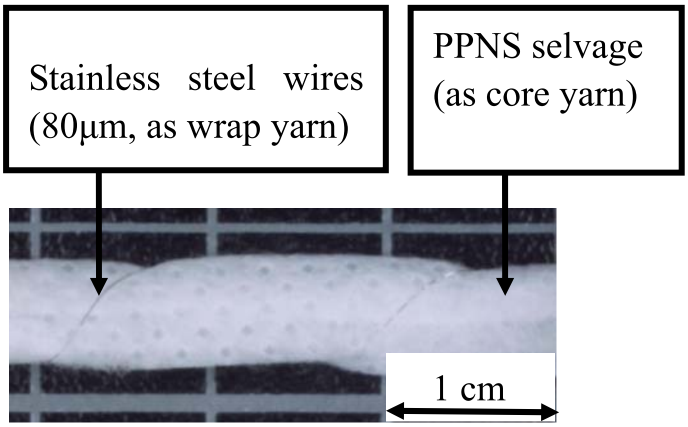


Figure 3 Type A-0.5 complex-ply yarn.

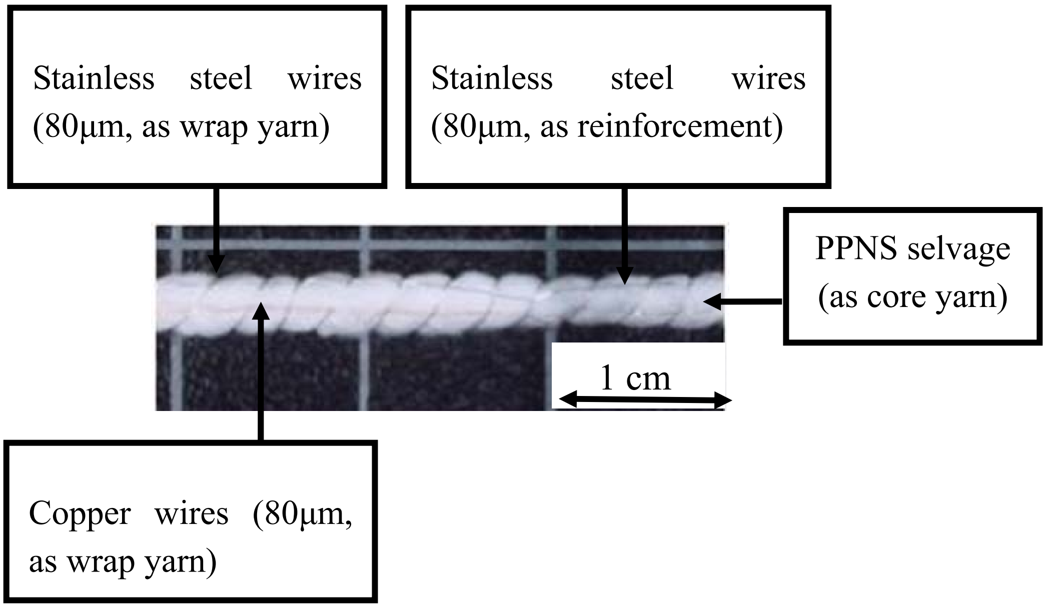


Figure 4 The C-4.5 complex-ply yarn is reinforced by 80 μm stainless steel wires.

Manufacturing parameters of the recycled PPNS/M complex-ply yarns

Three types of recycled PPNS/M complex yarns, A, B, and C, were fabricated using a rotor twister machine. All three types used recycled PPNS as the bulk of the core yarn; all three types used 80 μm stainless steel wires as the wrap yarn. Type A used no core reinforcement, type B used only steel reinforcement, and type C reinforced the core yarn with both 80 μm stainless steel wires and 80 μm copper wires. For all three types, the core yarn materials went through the center of the rotor twister; and the wrap yarn twisted around the core materials. The speed of the rotor twister was 8000 rpm and the speed of the winding roller was changed to fabricate complex yarns with five different wrap numbers: 0.5, 1.5, 2.5, 3.5, and 4.5 turns/cm.

Even though five different wrap numbers were tested, three wrap numbers were particularly typical, namely 0.5, 2.5, and 4.5. These three wrap numbers were used with the three levels of reinforcement, A, B, and C, to produce. Nine kinds of yarn specifically intended for weaving. Thus, the nine types of yarn were A-0.5, A-2.5, A-4.5, B-0.5, B-2.5, B-4.5, C-0.5, C-2.5, and C-4.5. Each sample of fabric woven in this research used one of these nine yarns as its weft yarn.

The manufacture of the recycled PPNS/M complex woven fabrics

Each of the nine varieties of complex-ply yarn was put into a Rapier loom as the weft yarn for a specific fabric. In all cases, the warp yarns were PVC-coated PET filaments. Figure 5 shows a fabric with a filling density of 7 picks/inch and a warp density of 26 ends/inch.

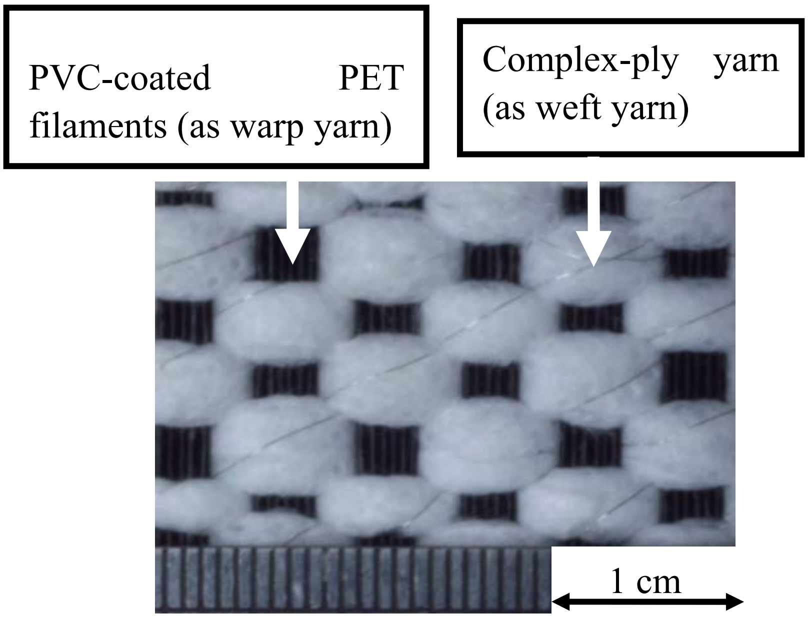


Figure 5 Fabric woven from C-0.5 and PVC-coated PET filaments.

Manufacturing parameters of the weft yarn for the recycled PPNS/M complex woven fabrics

Table 1 summarizes the manufacturing parameters of the weft yarn for the woven fabrics. The nine types of yarn were A-0.5, A-2.5, A-4.5, B-0.5, B-2.5, B-4.5, C-0.5, C-2.5, and C-4.5. Each sample of fabric woven in this research used one of these nine yarns as its weft yarn. After each variety of fabric had been produced, up to six layers of fabric were combined at controlled relative angles, known as lamination angles, for the final products.

Table 1 The manufacturing parameters of the weft yarns for the woven fabrics.

Complex-ply yarn type	Wrap numbers (turns/ cm)	Core yarn components	Wrap yarn
A	0.5, 2.5, 4.5	Recycled PPNS	Stainless steel wires
B	0.5, 2.5, 4.5	Recycled PPNS + stainless steel wires	Stainless steel wires
C	0.5, 2.5, 4.5	Recycled PPNS + stainless steel wires + copper wires.	Stainless steel wires

Testing methods

The surface resistivity measurement

This measurement procedure was based on JIS L1094 (Japanese Industrial Standard)[22]; the specimens were placed on a Teflon slab to ensure complete insulation. The tester was loaded with a 5 lb weight in order to keep the two parallel electrode plates in good contact with the surface of the fabrics to be tested. Each specimen was tested 20 times at different locations; for each specimen, the mean of the 20 values was recorded. Figure 6 shows the RT-1000 surface resistivity tester which was used in this experiment.

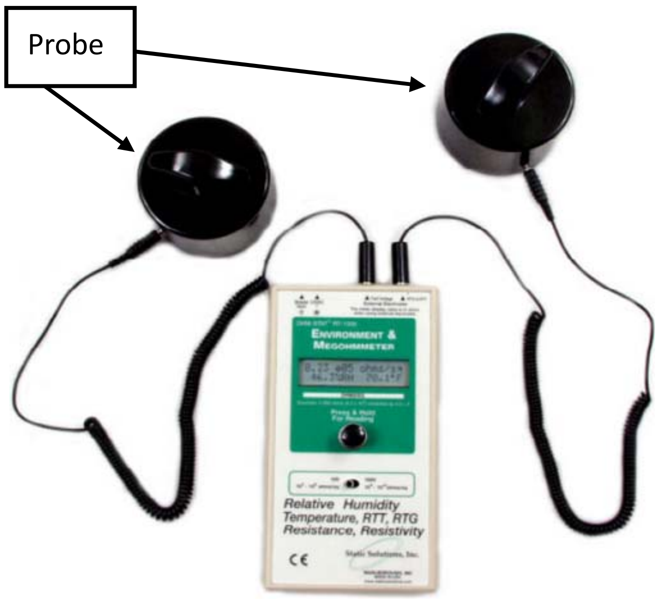


Figure 6 The surface resistivity tester.

EMSE measurement

Figure 7 shows a schematic of the test sample holder (model number EM-2107A) used for EMSE measurement. In this research, the scan frequency varied from 300 K to 3 GHz and the electromagnetic field was a far-field plane wave. Figure 8 shows the reference specimen on the left and the load specimen on the right. The reference specimen was shaped like a washer in order to rectify the EMSE tester; its EMSE was denoted as SE_{Ref}. After we measured the reference specimen, we tested the EMSE for each fabric specimen and recorded that value as SE_{Load}. We subtracted SE_{Ref} from SE_{Load} to find the correct EMSE [21].

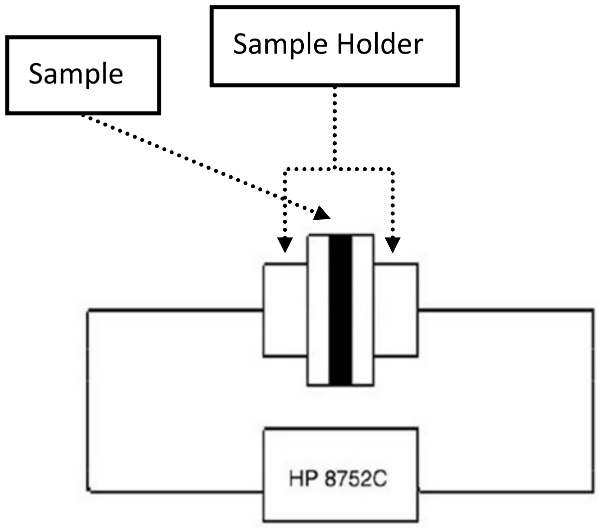


Figure 7 The sample holder.

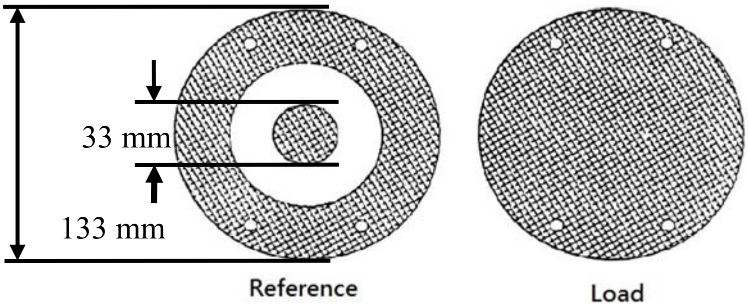


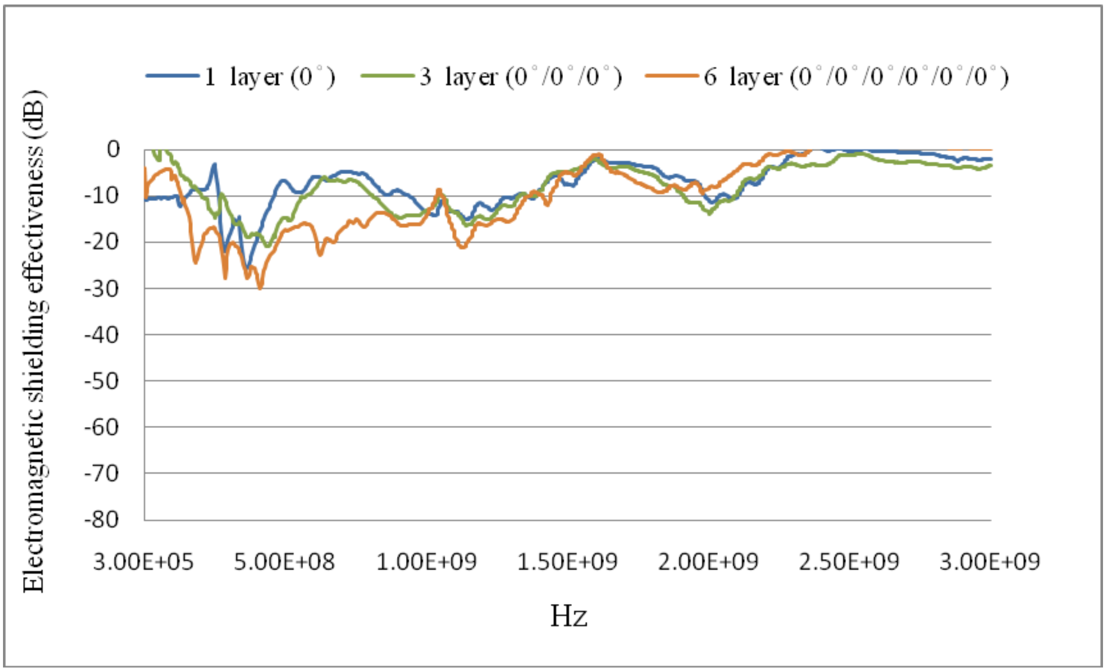
Figure 8 Reference and load specimens.

Results and Discussion

The influences of reinforcement materials and lamination numbers on EMSE levels

Figures 9 to 11 indicate that for most frequencies, fabrics with many layers had greater EMSE values than fabrics with few layers. Some waves that penetrated the outer layers of thick fabrics were reflected by deeper layers. For some low-frequency waves, the EMSE levels shown in Figures 9 to 11 reduced the waves by 20 dB. However, our intention is to provide at least 20 dB reductions across a wide range of frequencies. Because only weft yarns conducted electricity, high frequency waves were able to penetrate these fabrics.

A comparison of Figures 9, 10, and 11 shows that fabrics made with type C yarn had greater EMSE than fabrics made with type B yarn, which in turn had greater EMSE than fabrics made with type A yarn. This confirms that fabrics with high quantities of metal tend to reflect electromagnetic waves. However, possibly due to defects in the manufacturing process, EMSE was not uniform, and certain frequencies were shielded with unexpected effectiveness.



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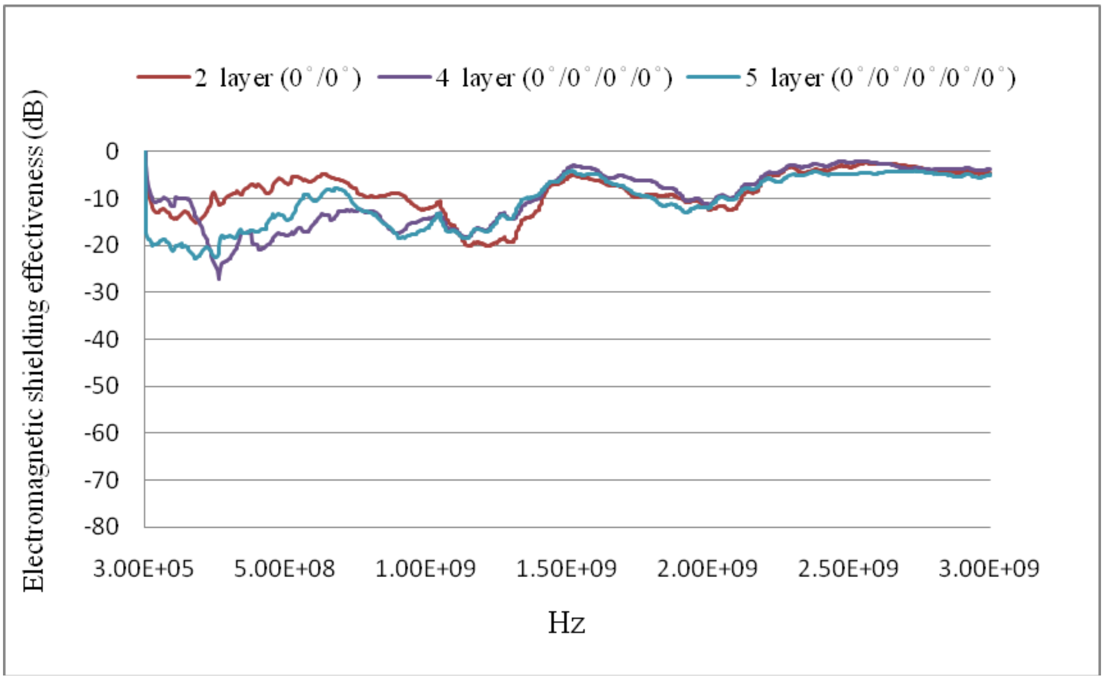
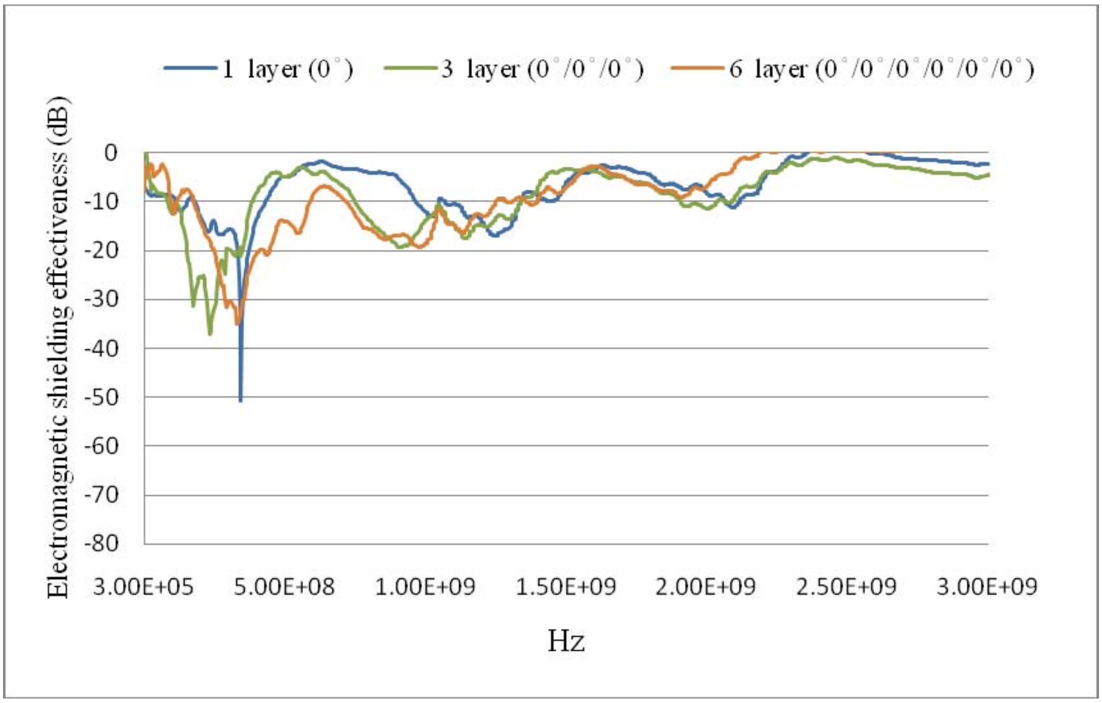


b

Figure 9 EMSE levels of fabrics woven with type A-4.5 complex ply yarns. (a) The fabrics are with 1, 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.



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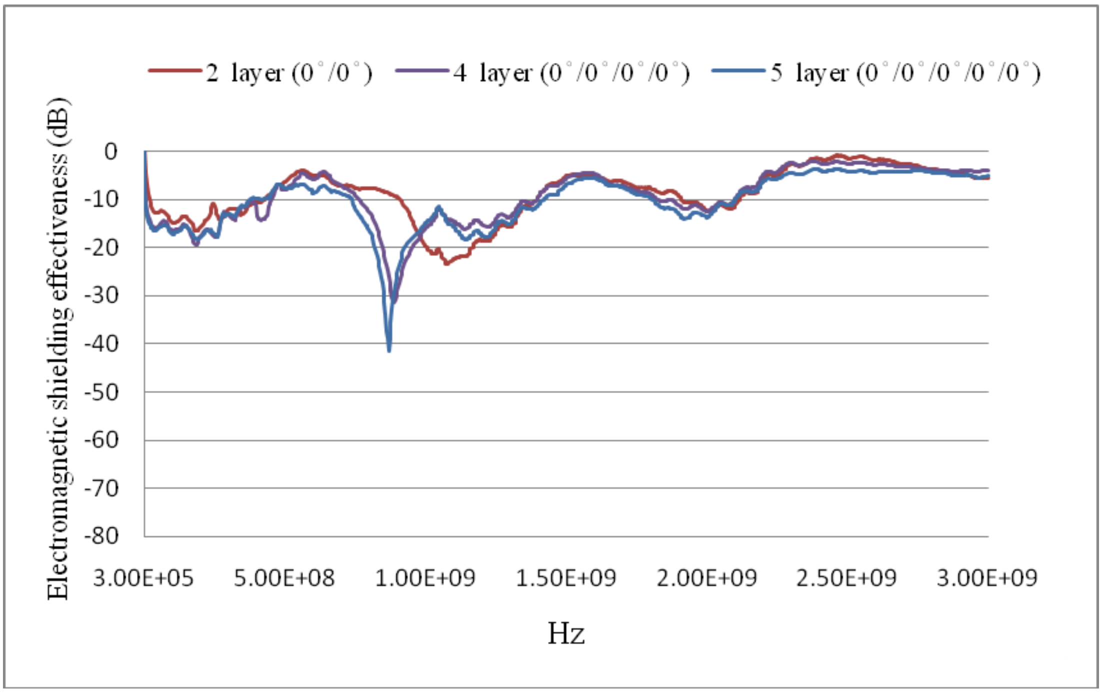

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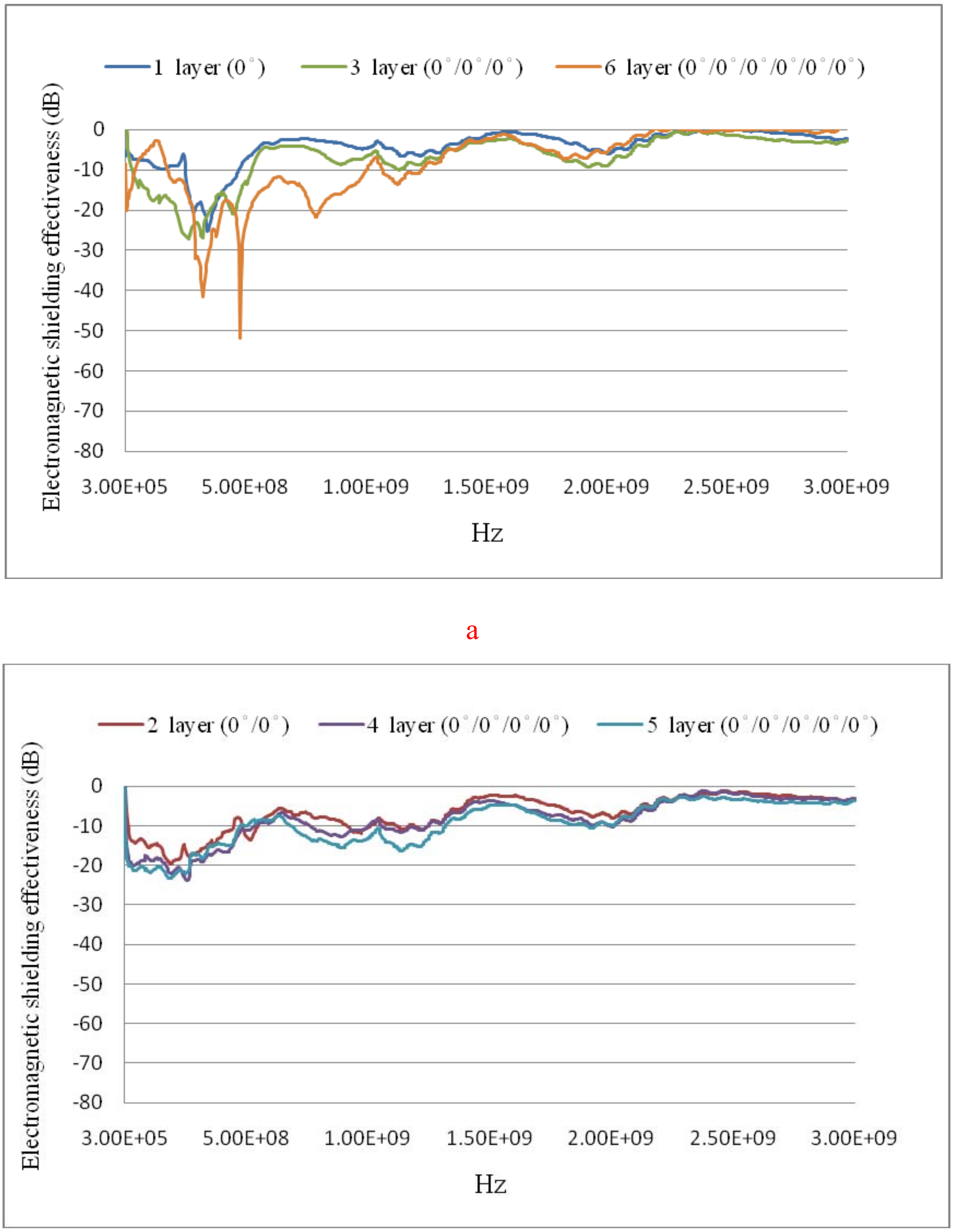
Figure 10 The EMSE levels of fabrics woven with type B-4.5 complex-ply yarns. (a) The fabrics are with 1, 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.



a

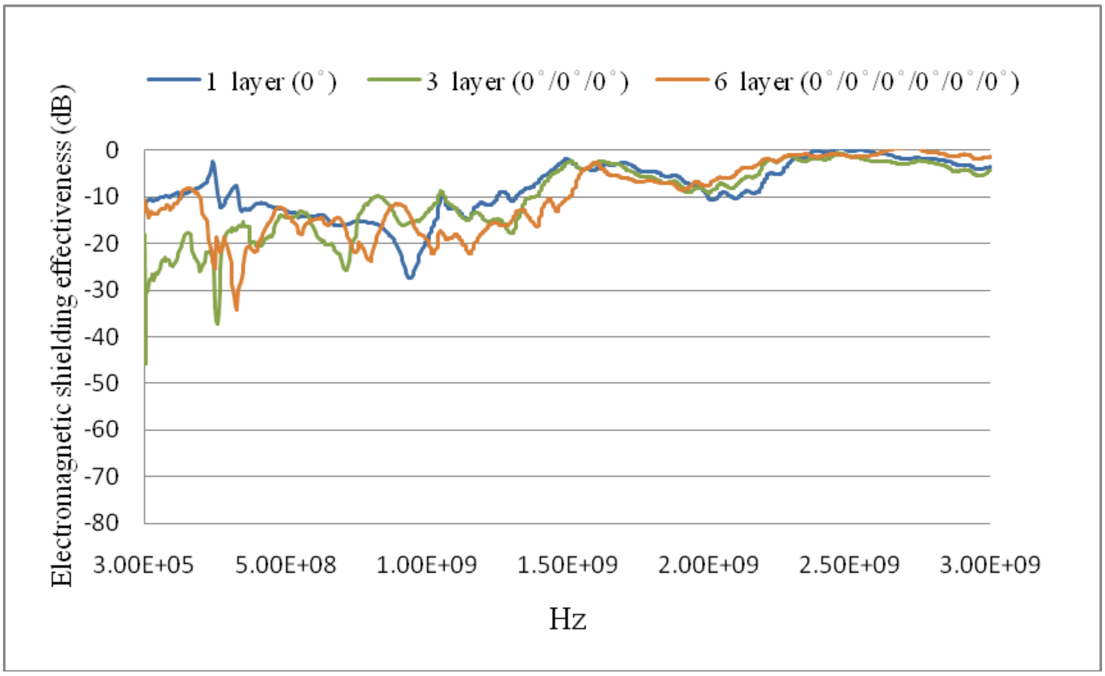
b

Figure 11 The EMSE levels of fabrics woven with type C-4.5 complex-ply yarns. (a) The fabrics are with 1, 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.

The influences of yarn wrap numbers and fabric lamination numbers on EMSE levels

Figures 12 to 14 further confirm that fabrics with high quantities of metal per unit area exhibit high EMSE levels. Fabrics with many layers shielded more than fabrics with few layers, and fabrics made with type C yarn shielded more than those made with other yarns did. All fabrics shown in Figures 12, 13, and 14 had 0° angles between layers and unevenly distributed wires; thus despite the presence of metal in the fabrics, some electromagnetic waves penetrated gaps. When the lamination angles and lamination numbers were constant, EMSE was high for fabrics with high wrap numbers.

Furthermore, fabrics with high quantities of metal exhibit high conductivity because many metal wires touch each other. While the optimum EMSE was measured for a fabric woven with type C-4.5 yarns, EMSE did not follow this trend for all frequencies. Anomalously good EMSE levels, measured for certain frequencies, may have been caused by fortuitous combinations of material characteristics and fabric structures.



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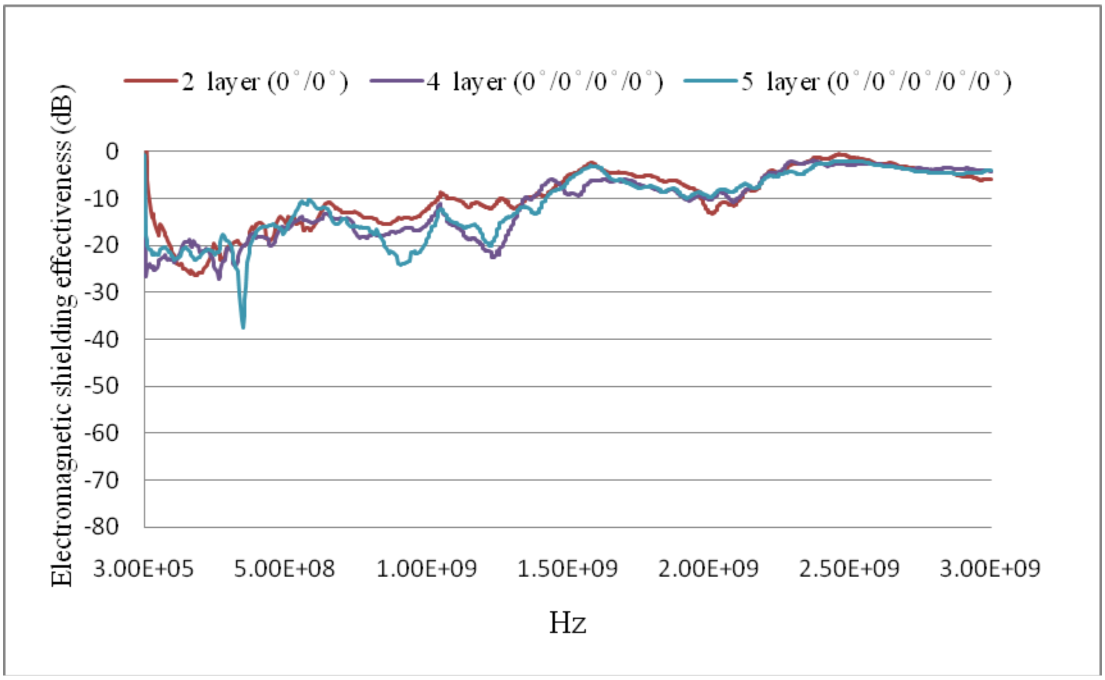

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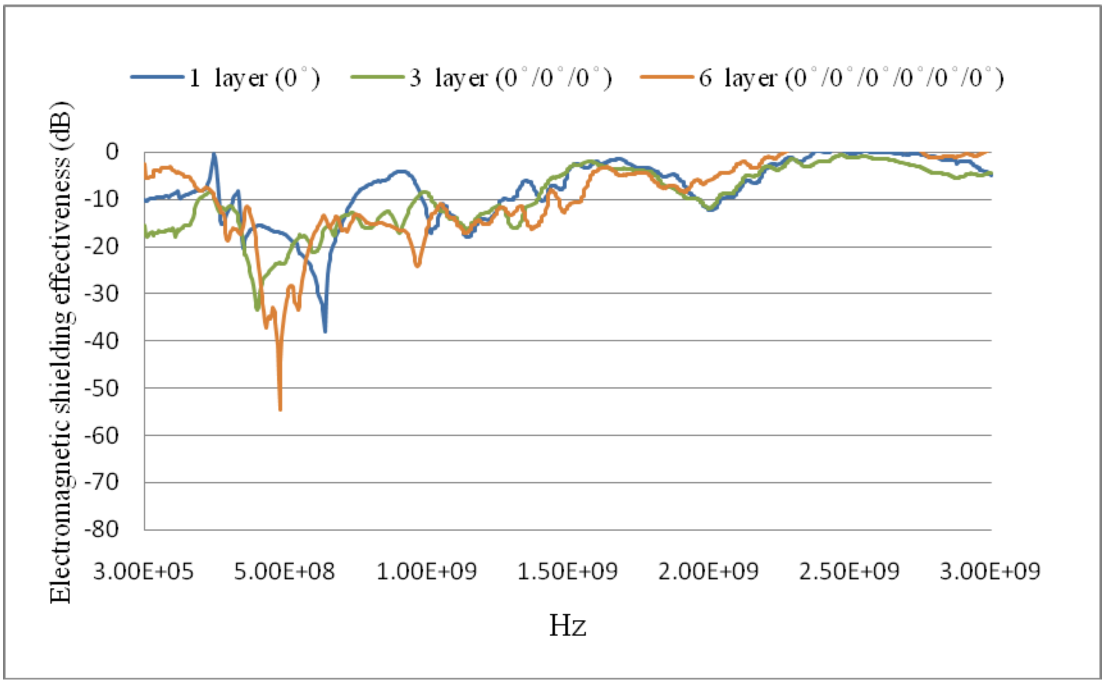
Figure 12 The EMSE levels of fabrics woven with type C-0.5 complex-ply yarns. (a) The fabrics are with 1, 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.



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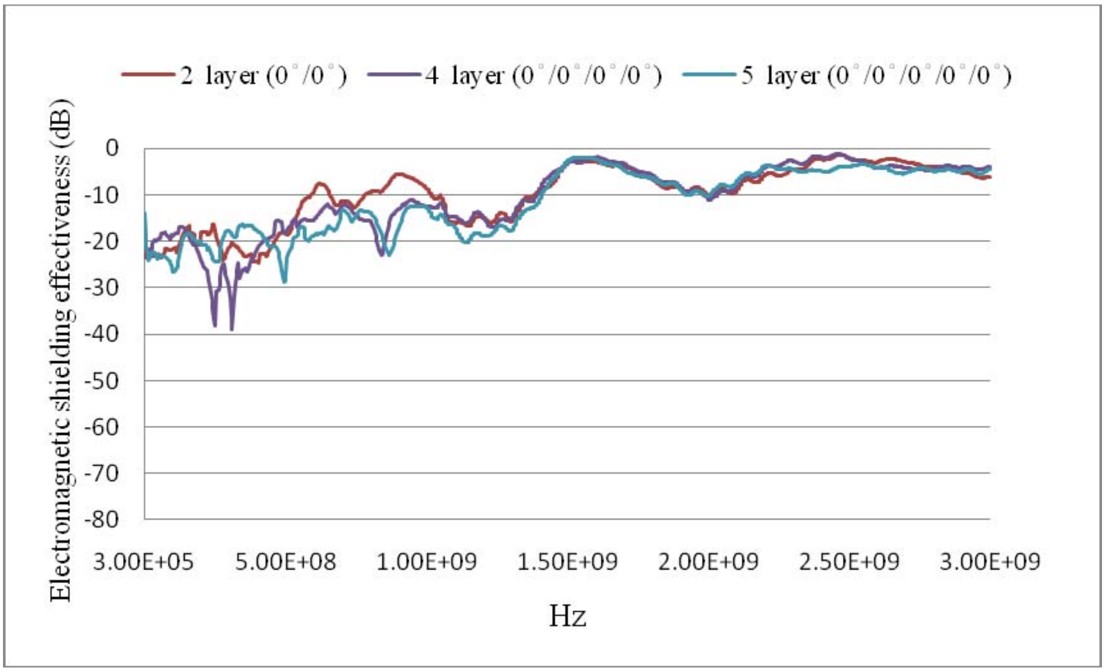

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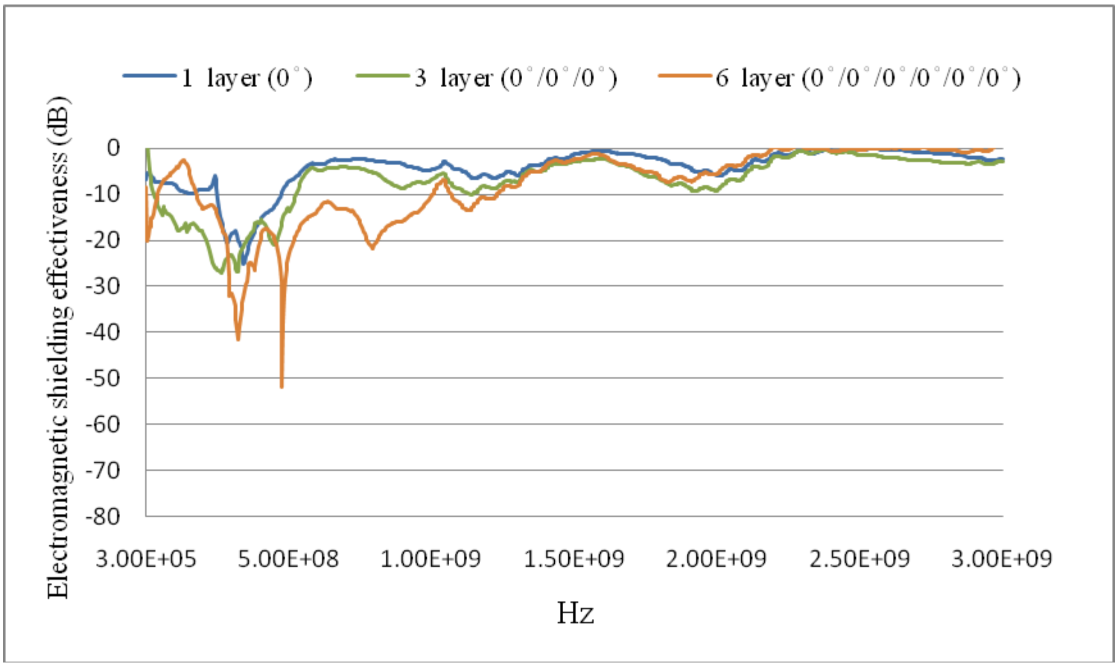
Figure 13 The EMSE levels of fabrics woven with type C-2.5 complex-ply yarns. (a) The fabrics are with 1, 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.



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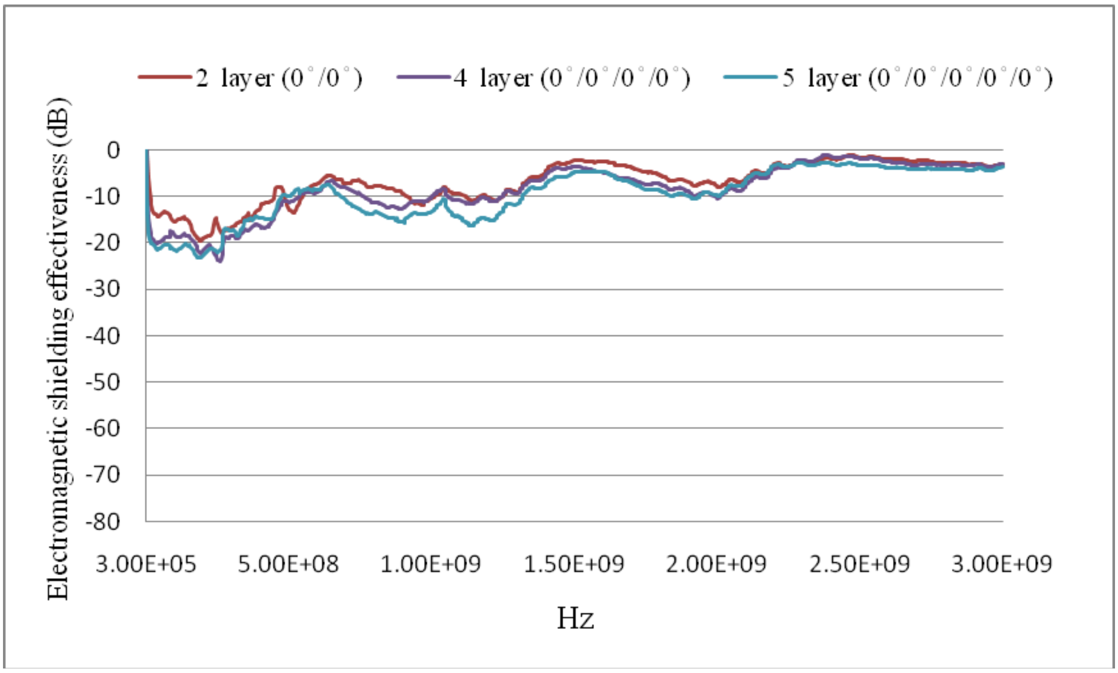

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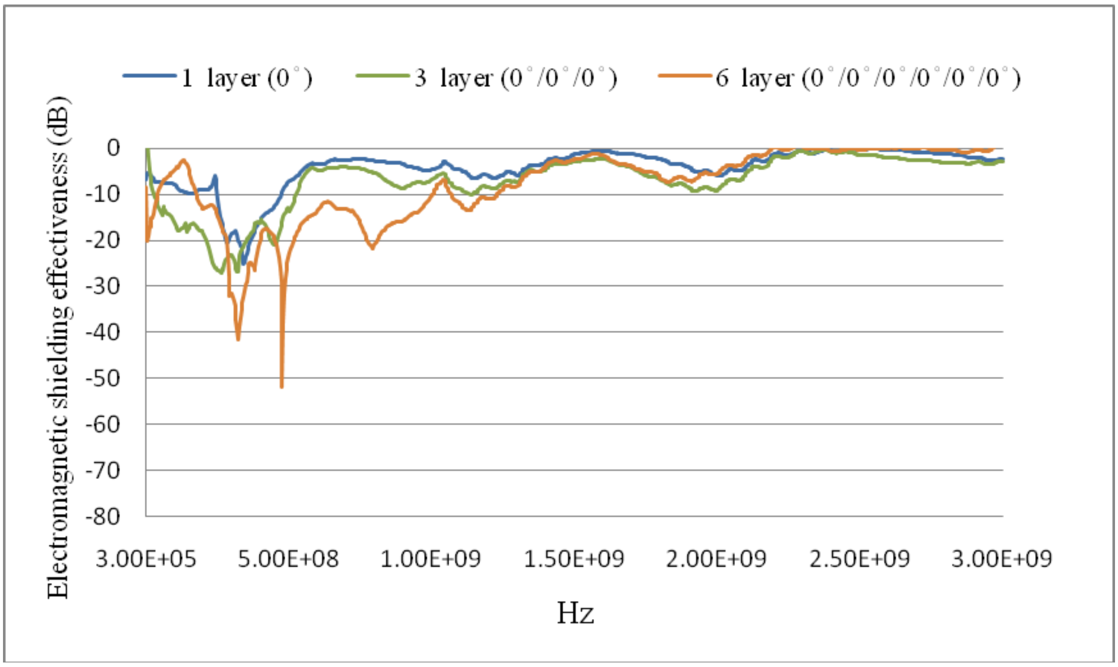
Figure 14 The EMSE levels of fabrics woven with type C-4.5 complex-ply yarns. (a) The fabrics are with 1, 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.

The influences of lamination angles and lamination numbers on EMSE levels

Figures 15 to 17 show a dramatic range of EMSE levels for fabrics with different lamination numbers and lamination angles. Large differences in lamination angles produced large areas covered by evenly dispersed metal wires. Fabrics with 90° lamination angles had the optimal metal wire contact, optimal conductivity, and optimal EMSE; fabrics with 0° laminations angles showed the worst performance. Figures 9 through 15 show poor EMSE performance at high frequencies. Figure 16 and Figure 17 show excellent EMSE performance, even at high frequencies. One possible explanation might be that the metal wires formed a conductive net that affected EMSE. While adding extra layers of fabric (with change in lamination angle) is an obvious way to increase EMSE, these results show that variations in lamination angles make additional layers much more effective.



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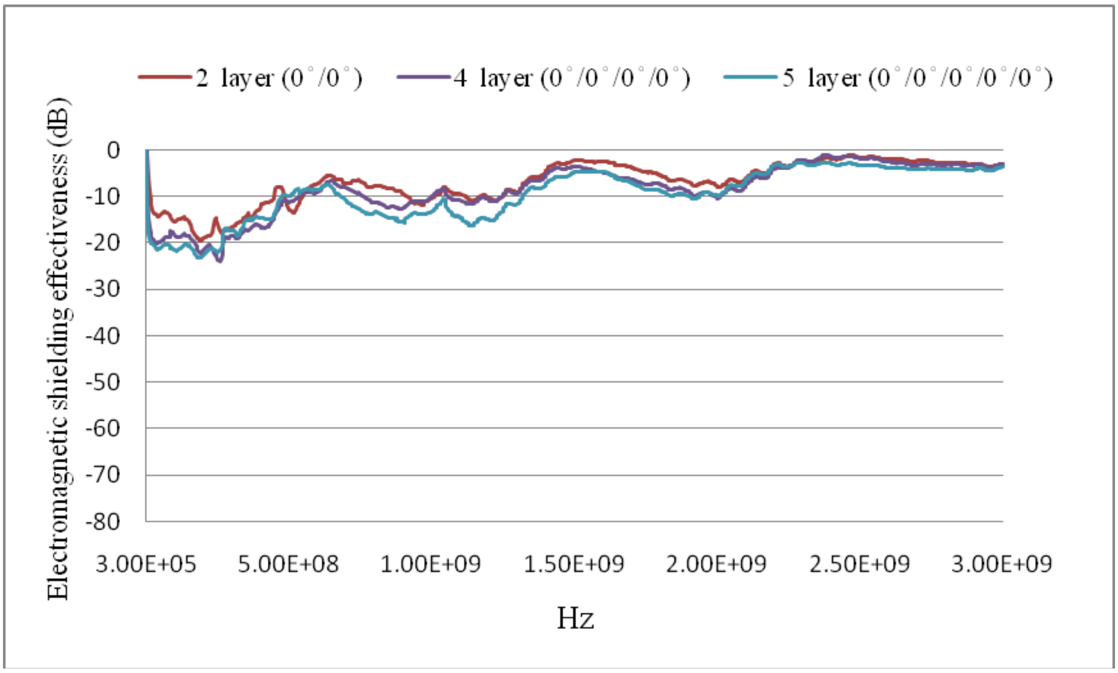

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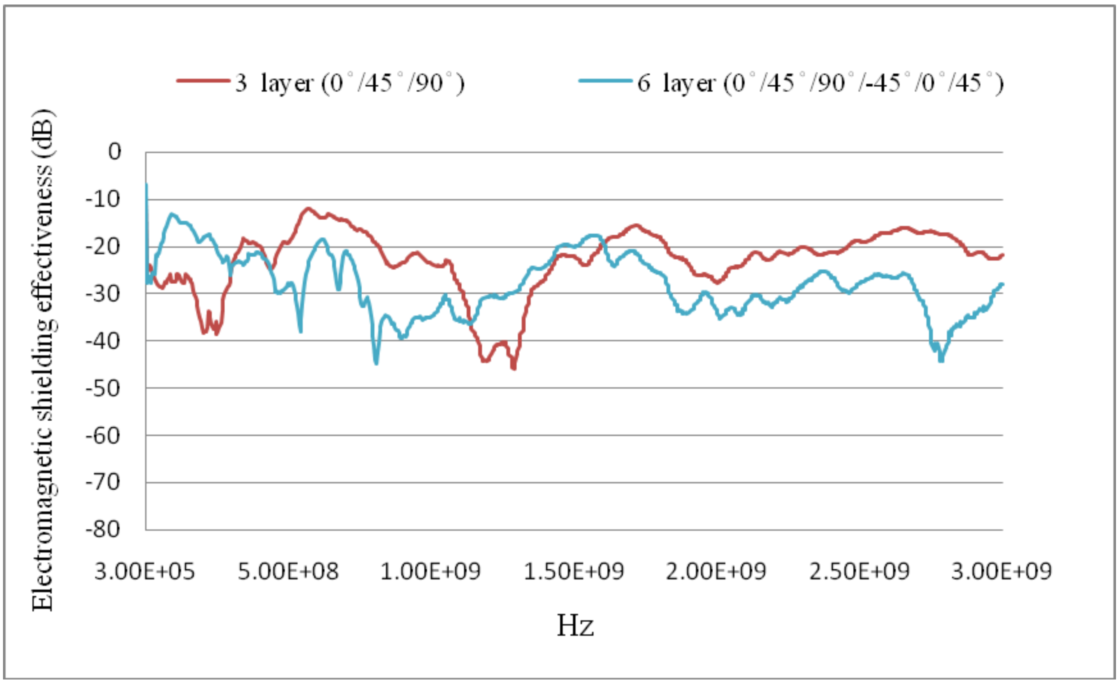
Figure 15 The EMSE levels for C-4.5 fabrics with no variation in lamination angle. (a) The fabrics are with 1, 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.



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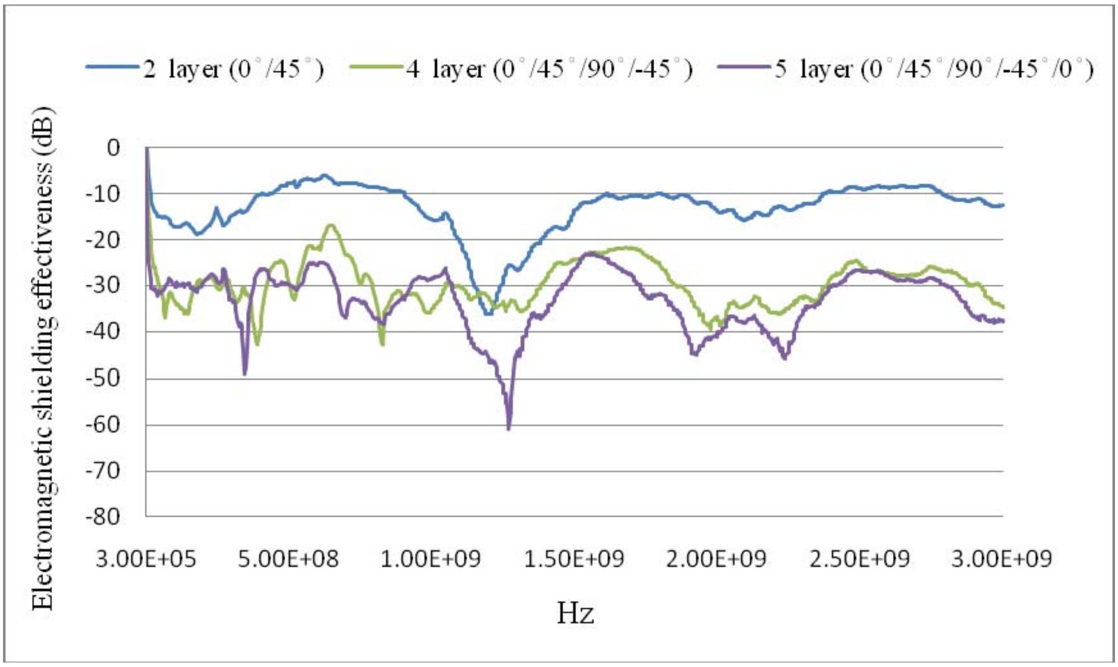

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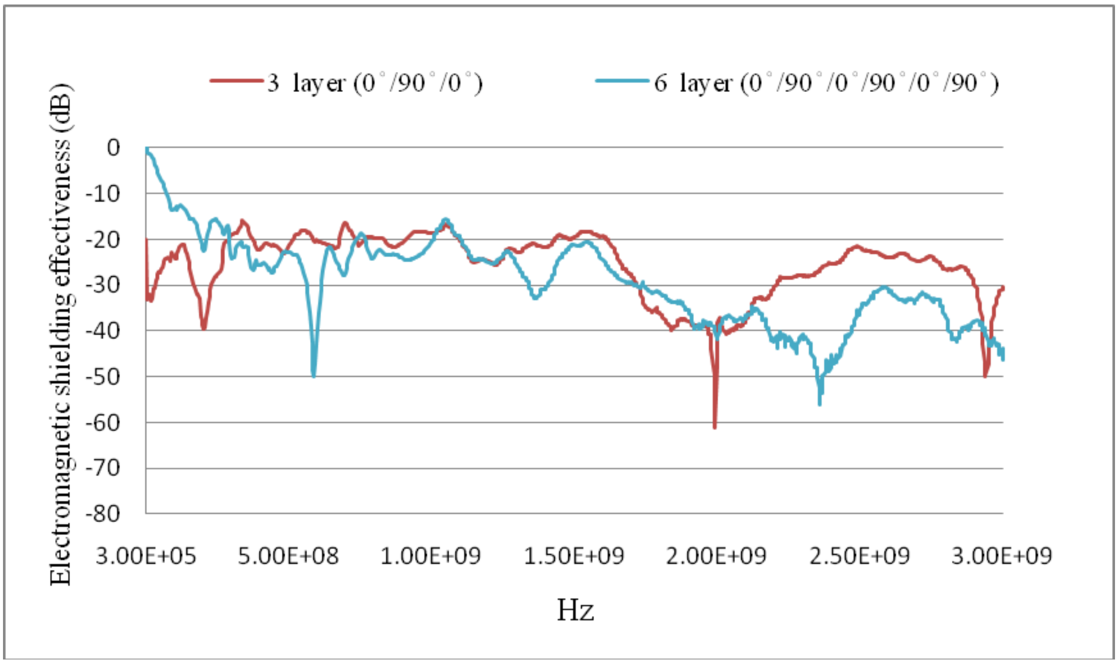
Figure 16 The EMSE levels for C-4.5 fabrics with 45° variations in lamination angles. (a) The fabrics are with 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.



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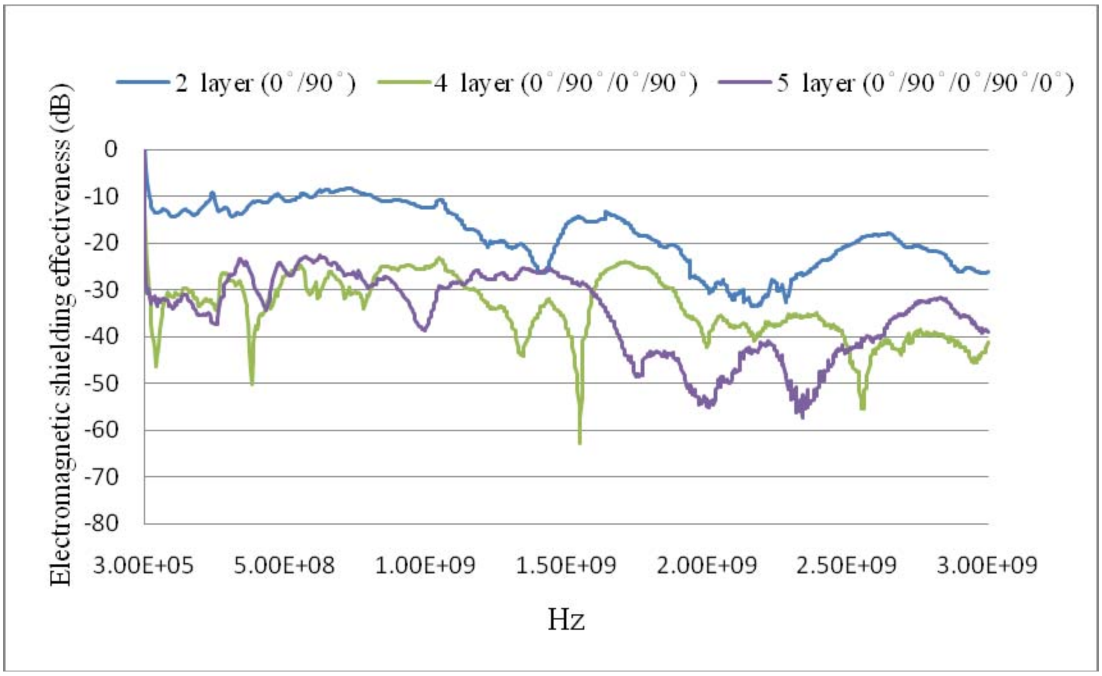

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Figure 17 The EMSE levels for C-4.5 fabrics with 90° variations in lamination angles. (a) The fabrics are with 3, and 6 layers. (b) The fabrics are with 2, 4, and 5 layers.

The influences of yarn wrap numbers and reinforcements on surface resistivity levels

The PVC-coated PET warp yarns of these fabrics were electrical insulators; the metal wires in the weft yarns were electrical conductors. Tables 2 to 4 show that the warp direction and weft direction of these fabrics displayed significant differences in surface resistivity levels. When measured in the weft direction, all fabrics showed less than $10^{2.2}$ Ω/sq of surface resistivity. The fabrics containing the largest amounts of metals showed the lowest surface resistivity in the weft direction. Both yarn type and wrap number affected surface resistivity measured in the weft direction. Surface resistivity levels measured in the warp direction were always relatively high, but did not display a clear correlation with wrap numbers. Some of the differences of surface resistivity measured in the warp direction may have been measured when the metal probe touched the weft yarns. Fabrics made with type C yarns, with both copper and stainless steel wires, showed lower surface resistivity levels than fabrics made with type B yarns, which had only stainless steel wires. The lowest surface resistivity found in this study, 28.2 Ω/sq, was measured for a fabric specimen woven with type C yarns.

Table 2 Surface resistivity levels of single-layer fabrics with type A yarns.

Wrap number turn/cm	Weft direction log (Ω/square)	Warp direction log (Ω/square)
0.5	2.14±0.08	11.46±0.24
2.5	2.04±0.04	10.36±0.25
4.5	1.94±0.17	10.19±0.36

Table 3 Surface resistivity levels of single-layer fabrics with type B yarns.

Wrap number turn/cm	Weft direction log (Ω/square)	Warp direction log (Ω/square)
0.5	1.64+0.26	9.74+0.38
2.5	1.49+0.15	10.25+0.2
4.5	1.48+0.26	9.51+0.24

Table 4 Surface resistivity levels of single-layer fabrics with type C yarns.

Wrap number turn/cm	Weft direction log (Ω/square)	Warp direction log (Ω/square)
0.5	1.56+0.08	9.99+0.24
2.5	1.47+0.8	10.41+0.27
4.5	1.45+0.08	9.74+0.28

Conclusions

In this research, we made stainless steel wires, copper wires and recycled PPNS into complex-ply yarns by means of a rotor twister machine; furthermore, these yarns were woven into fabrics that displayed useful levels of EMSE. Fabrics woven from type C-4.5 yarns showed the lowest surface resistivity, 28.7 Ω. Fabrics that contained large amounts of metal had low surface resistivity levels. Fabrics with many layers tended to reflect electromagnetic waves. Fabrics with varied lamination angles had large percentages of their cover areas shielded by metal. In particular, six-layer fabric woven from type C-4.5 yarns, with 0°/90°/0°/90°/0°/90° lamination angles, had an EMSE of 56.1 dB. This research protects the environment by recycling industrial by-products into useful raw materials, and the woven fabrics produced by our methods can protect human health by reducing undesirable electromagnetic radiation. Moreover, complex-ply yarns can be made with various fibrous materials, and can be incorporated into products with multiple functions. We intend to use these techniques with other materials to satisfy the future requirements of the textile industry.

Acknowledgements

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Literature Cited

1. Graves, V., A Commodity Plastic Reaches Record highs in 1994 Production, *Modern Plastic Encyclopedia*, PB-62 (1996)

2. Steven, B. W., Fiber Science, Prentice Hall, Englewood Cliffs, NJ07632, 1-3, (1995)

3. Dharmadhikary, R. K., Gilmore, T. F., Davis, H. A., Batra, S. K., Thermal Bonding of Nonwoven Fabrics, *Textile Progress*, **26**(2), 24-32 (1995).

4. Lou, C. W., Fabrication and Electric Properties of the Ply Yarn and Its Fabrics Produced by Polypropylene Nonwoven Selvage, unpublished master's thesis, university of Feng Chia, (2001).

5. Green, L. M., Miller, A. B., Villeneuve, P. J., Agnew, D. A., Greenberg, M. L., Li, J., Donnelly, K. E., A case-control study of childhood leukemia in southern Ontario, Canada, and exposure to magnetic fields in residences., *Int. J. Cancer*, **82**(2), 161-170 (1999).

6. Green L. M., Miller, A. B., Agnew D. A., Greenberg M. L., Li J., Villeneuve P. J., Tibshirani R., Childhood leukemia and personal monitoring of residential exposures to electric and magnetic fields in Ontario, Canada., *Cancer Causes Control*, **10**(3), 233-243 (1999).

7. Habash, R. W. Y., Electromagnetics - the uncertain health risks, *Potentials, IEEE*, **22**(1), 23-26 (2003).

8. Kheifets, L.Shimkhada, R., Childhood leukemia and EMF: Review of the epidemiologic evidence, *Bioelectromagnetics*, **26**(7), 51-59 (2005).

9. Kheifets, L. I., Electric and magnetic field exposure and brain cancer: a review., *Bioelectromagnetics*, **22**(5), 120-131 (2001).
10. Wartenberg, D., Residential EMF exposure and childhood leukemia: Meta-analysis and population attributable risk, *Bioelectromagnetics*, **22**(5), 86-104 (2001).
11. Olden, K., NIEHS report on health effects from exposure to power-line frequency electric and magnetic fields, *National Institute of Environmental Health Sciences*, NC 27709 (1999).
12. Lin, J. H., Chang, C. W., Lou, C. W., Hsing, W. H., Mechanical Properties of Highly Elastic Complex Yarns with Spandex Made by a Novel Rotor Twister, *Text. Res. J.,* **74**(6), 480-484 (2004).
13. Chen, A. P., Lin, C. M., Lin, C. W., Hsieh, C. T., Lou, C. W., Young, Y. H., Lin, J. H., Electromagnetic Shielding Effectiveness and Manufacture Technique of Functional Bamboo Charcoal/Metal Composite Woven, *Adv. Mat. Res.*, **123-125**, 967-970 (2010).
14. Chen, H. C., Lee, K. C., Lin, J. H., Koch, M., Comparison of electromagnetic shielding effectiveness properties of diverse conductive textiles via various measurement techniques, *J. Mater. Process. Technol.,* **192-193**, 549-554 (2007).

15. Cheng, K. B., Ramakrishna, S., Lee, K. C., Electromagnetic shielding effectiveness of copper/glass fiber knitted fabric reinforced polypropylene composites, *Compos. Part A Appl. Sci. Manuf.,* **31**(10), 1039-1045 (2000).

16. Lin, C. W., Lin, J. H., Manufacture and Application of High-Performance Geogrids with PP/PET Composite Covered Yarn, *Text. Res. J.,* **75**(6), 453-457 (2005).

17. Chen, H. C., Lee, K. C., Lin, J. H., Electromagnetic and electrostatic shielding properties of co-weaving-knitting fabrics reinforced composites, *Compos. Part A Appl. Sci. Manuf.,* **35**(11), 1249-1256 (2004).

18. Lin, J. H., Lou, C. W., Electrical Properties of Laminates Made from a New Fabric with PP/Stainless Steel Commingled Yarn, *Text. Res. J.,* **73**(4), 322-326 (2003).

19. Lou, C. W., Lin, C. M., Chen, A. P., Yang, Y. C., Chen, C. P., Lin, J. H., Manufacturing Technique and Physical Property of Metal Wires/ PP Nonwoven Selvedges Complex Ply Yarns and Knitted Fabrics, Adv. *Mat. Res.,* **97-101**, 1797-1800 (2010).

20. Chen, A. P., Lin, C. M., Hsieh, C. T., Yang, Y. C., Lou, C. W., Lin, J. H., Mechanical Evaluation of the Production of Bamboo Charcoal/ Stainless Steel Complex Yarns and Knitted Fabrics, *Adv. Mat. Res.,* **97-101,**

1786-1789 (2010).

21. Yang, S., Lozano, K., Lomeli, A., Foltz, H. D., Jones, R., Electromagnetic interference shielding effectiveness of carbon nanofiber/LCP composites, *Compos. Part A Appl. Sci. Manuf.*, **36**(5), 691-697 (2005).

22. JIS L1094 refers to Japanese Industrial Standard, and it is a standard which stipulates the testing methods for electrostatic propensity of woven and knitted fabrics.