The Reflection, Transmission, and Absorption of Electromagnetic Waves in Stainless Steel/Polyester Fabrics

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Abstract

The reflection, transmission, and absorption behaviors of electromagnetic waves in fabrics have been studied by a network analyzer at 30 MHz~1500 MHz and 0 dBm. The fabrics used in this study were made by a stainless steel/polyester spun yarn. The component ratios of stainless steel/polyester fiber in spun yarns were 10/90, 20/80, 30/70, and 40/60. There were two kinds of fabrics, which were meshed fabrics in density of 7×7 picks per inch and the woven fabrics in density of 80×65 picks per inch. The EMI shielding characteristics were divided into three behaviors, such as reflection, transmission, and absorption behaviors. The results showed that electromagnetic interference shielding effectiveness (EMI SE) in woven and meshed fabrics rose with an increase of frequency. It was found that reflection is a major factor of EMI SE for higher conductive fabrics, and absorption is a major factor of EMI SE for lower conductive fabrics. A decrease of reflectance and an increase of absorbance resulted from an increase of frequency.

Keywords: reflection, transmission, and absorption of electromagnetic waves, stainless steel/polyester fabrics

1. Introduction

The use of electronic equipment causes electromagnetic radiation, which results in an unwanted electromagnetic interference (EMI). EMI can obstruct the performance of electronic or electrical equipment. There is also an important issue about the potential health hazards (cancer) associated with exposure to electromagnetic fields. An incident electromagnetic wave is partially attenuated through reflection on the surface of a material, absorption by the material, or multiple internal reflections inside the material. The rest of the wave is then transmitted through the material [1]. The primary mechanism of EMI shielding, reflection requires the existence of mobile charge carriers (electrons or holes) which interact with the electromagnetic radiation. The second mechanism, absorption, requires electric and/or magnetic dipoles which interact with the electromagnetic fields. The electric dipoles provided by materials have high dielectric constants or magnetic permeability [2]. Reflectance decreases with an increase of frequency, the absorbance increases with an increase of frequency. The absorption is proportional to the thickness of the shield. The third mechanism of attenuation is multiple reflections. This refers to the reflections on various surfaces or interfaces in the shield. This mechanism requires the presence in the shield of a large surface area or interface area as in a porous or foam material, or a composite material containing filler which has a large surface area in the shield [3]. Total EMI shielding effectiveness (EMI SE) of a material is, therefore, the sum of shielding effectiveness (SE) resulting from the three shielding mechanisms. The relative shielding efficiency by reflection and absorption is an important determinant of practical application [4-6]. EMI shielding by absorption rather than reflection is more important for many applications at the present time.

Various researchers have reported the results of their investigation on conductive composite materials in EMI shielding characteristics. N. C. DAS et al. studied conductive rubber-based composites blend filled with carbon black and short carbon fiber (SCF). It has been observed that the shielding effectiveness of the composites is frequency dependent and increases with increasing frequency [7]. M. S. Kim et al. found that the composite shielded EMI by absorption as well as reflection, and that EMI shielding through reflection increased with the electrical conductivity [8]. Samples consisting of an electrometric matrix containing different kinds of active materials in particulate form were prepared for reflectivity measurements by M. S. Pimho [9]. The electromagnetic shielding properties of epoxy resin composites containing short carbon fibers coated with a layer of non-conducting polyaniline base have been studied. The absorption part of shielding efficiency rises with the frequency of electromagnetic radiation [10]. Y. Yang and M. C. Gupta inferred the primary EMI shielding mechanism of such CNT-PS foam composites was demonstrated and ascribed to the reflection of electromagnetic radiation [11].

According to the above studies, reflection, transmission, and absorption of electromagnetic waves in materials have gradually become respected. Most studies, however, have focused on filled composites and less on conductive fabrics. Fabrics composed of metal fibers and synthetic fibers possess high conductivity. They are lightweight, flexible, and are manufactured easily. They have many useful and practical applications. For the purpose of this present study, the stainless steel fibers as conductive materials were spun with polyester fibers to form stainless steel/polyester (SSF/PET) spun yarn. Textile technology was carried out to fabricate meshed fabrics and woven fabrics. Reflection, transmission and absorption of electromagnetic waves in fabrics were investigated.

2. Experiment

2.1 Specimen preparation

Stainless steel fibers, 12 μm in diameter, were spun with polyester fibers in this study. The component ratios of stainless steel and polyester spun yarns were 10/90, 20/80, 30/70, and 40/60. They were used to form meshed fabrics in 7×7 picks per inch and woven fabrics in 80×65 picks per inch. Sample codes are given in Table 1.

Table 1 Sample Code

Component ratio (SSF/PET) / Fabric	10/90	20/80	30/70	40/60
Meshed fabric	M10	M20	M30	M40
Woven fabric	W10	W20	W30	W40

2.2 Measurement of EMI SE

EMI SE was obtained following ASTM D 4935-89 using a network analyzer (ADVENTEST R3765CG) and set over a frequency range of 30 MHz~1500 MHz and a power of 0 dBm. EMI SE value expressed in dB was calculated from the ratio of the incident to transmitted power of the electromagnetic wave as in the following Eq.

$$SE = 10\log\left|\frac{P_1}{P_2}\right| = 20\log\left|\frac{E_1}{E_2}\right| \qquad (decibels, dB) \qquad (1)$$

where $P_1(E_1)$ and $P_2(E_2)$ are the incident power (incident electric field) and the transmitted power (transmitted electric field), respectively. The reflectance (R_e) and the transmittance (T_r) of the material were measured and the absorbance (A_b) was calculated using the following Eq.

$$A_b = 1 - T_r - R_e \qquad (2)$$

where, R_e and T_r are the square of the ratio of reflected (E_r) and transmitted (E_t) electric fields to the incident electric field (E_i), respectively, as in the following Eqs. :

$$R_e = \left|\frac{E_r}{E_i}\right|^2 = \left|S_{11}(orS_{22})\right|^2 \qquad (3)$$

$$T_r = \left|\frac{E_t}{E_i}\right|^2 = \left|S_{21}(orS_{12})\right|^2 \qquad (4)$$

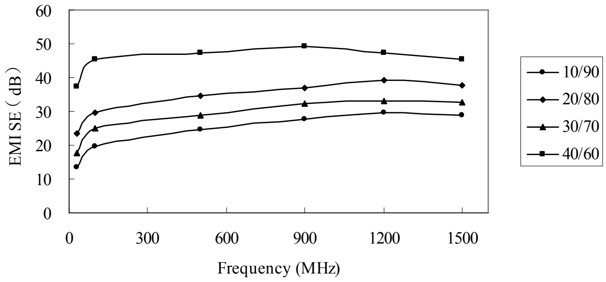
R_e and T_r were obtained by the measurement of S-parameters, S_{11} (or S_{22}) and S_{12} (or S_{21}) for the reflection and the transmission, respectively.

3. Result and discussion

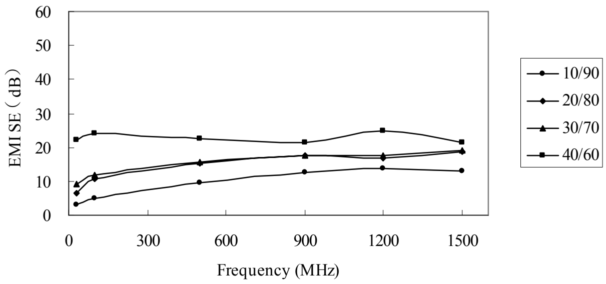
3.1 Electromagnetic shielding effectiveness

According to ASTM D4935-89, the EMI SE of a planar material is expressed as in Eq. 1. It specifies how much signal is blocked by the shielding medium. An EMSE of 10 means 90% of signal is blocked and 20 means 99% of signal is blocked.

Fig. 1 shows the variation in EMI SE of woven and meshed fabrics with different component ratios of stainless steel/polyester spun yarn at incident frequency from 30 MHz to 1500 MHz. As incident frequency increased, the EMI SE of all fabrics increased. W40 had 40 dB in EMI SE, and W10 had 30 dB in high frequency. The EMI SE of woven fabrics was higher than meshed fabrics. It may be that the lower conductivity from the lower network density of conductive fibers in meshed fabrics caused the EMI SE to be lower.



(a) Woven fabrics

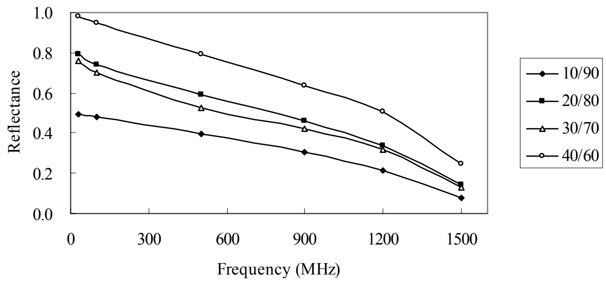


(b) Meshed fabrics

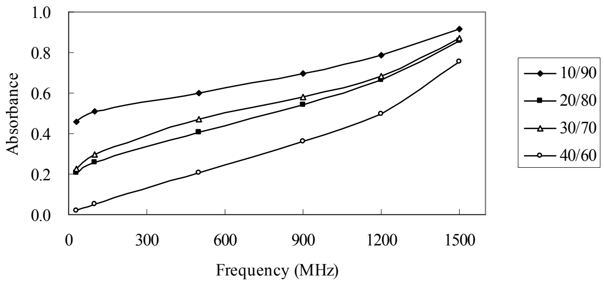
Fig. 1. Variation of EMI SE in woven and meshed fabrics with different component ratios of stainless steel/polyester spun yarn at incident frequency from 30 MHz to 1500 MHz

3.2 EMI shielding characteristics of fabrics

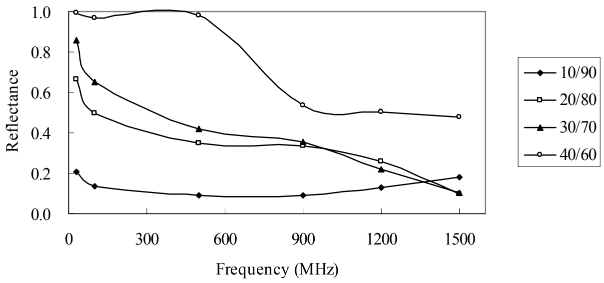
The reflectance and absorbance of woven fabrics and meshed fabrics were compared in Fig.2.



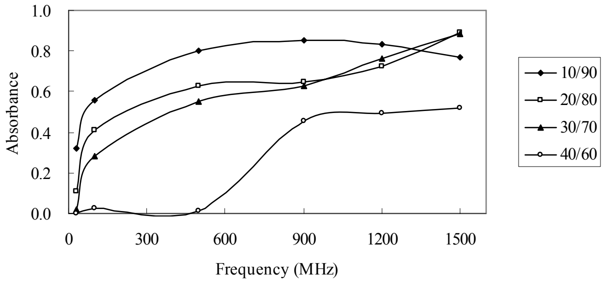
(a) Reflectance of woven fabrics



(b) Absorbance of woven fabrics



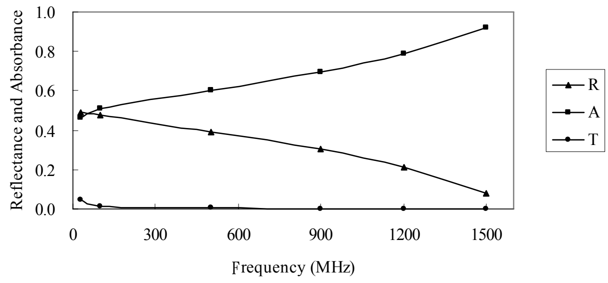
(c) Reflectance of meshed fabrics



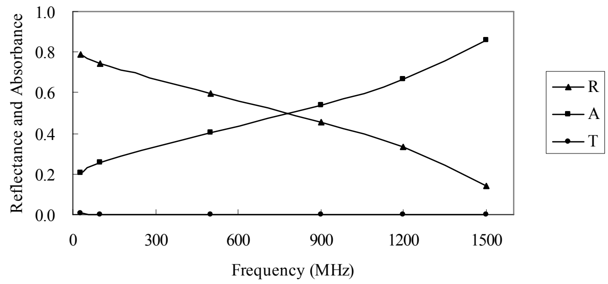
(d) Absorbance of meshed fabrics

Fig. 2. Reflectance and absorbance of electromagnetic waves in woven and meshed fabrics were a function with frequency from 30 MHz to 1500 MHz

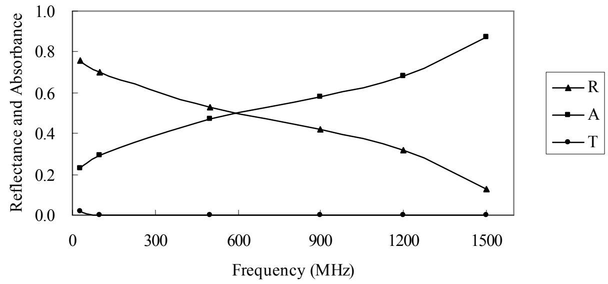
It can be seen that a rising frequency results in a decrease in reflectance and an increase in absorbance (see Fig. 2). This is due to reflectance by mismatching impedance between materials and electromagnetic waves, and absorbance by skin depth of materials. At any frequency, the skin depth is defined as the surface thickness of a material in which 1-1/e or 63.2 percent of the current is flowing. Impedance of high conductivity material is low and the impedance difference between material and air is large, so that reflectance is great. The reflectance decreased when impedance difference were smaller. This was due to increased material impedance with an increase of frequency. The absorbance increased because skin depth became larger with an increase in frequency. The lower component ratios of stainless steel fibers led to a lower material impedance, and a higher reflectance. EMI SE is the total outcome by reflectance and absorbance. Therefore, if reflectance is higher then absorbance is lower.



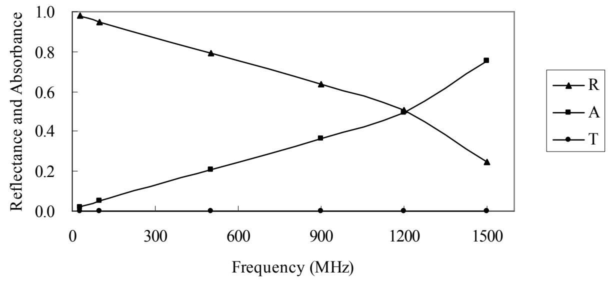
(a) W10



(b) W20



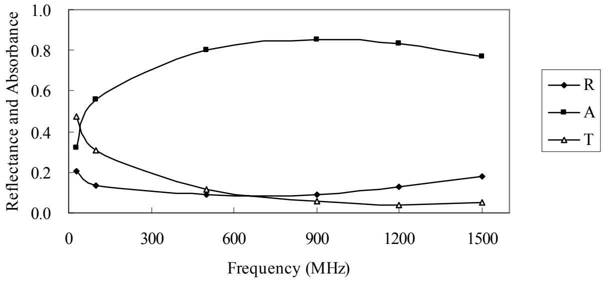
(c) W30



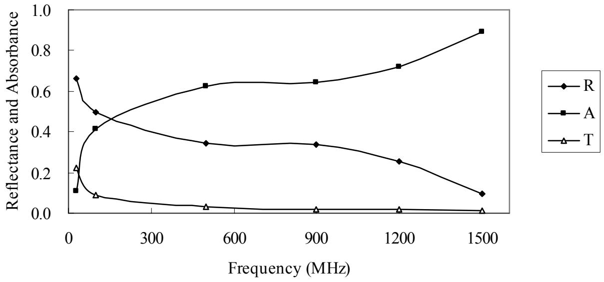
(d) W40

Fig. 3. Reflectance, absorbance, and transmittance in woven fabrics were investigated

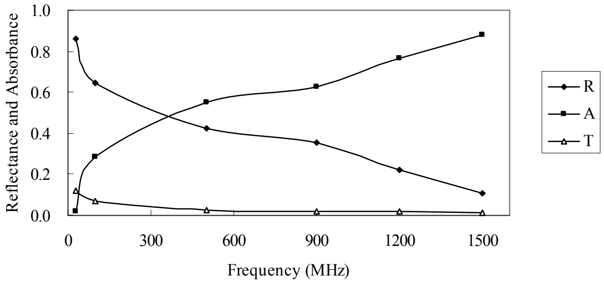
The reflectance, absorbance, and transmittance of stainless steel/polyester woven fabrics with different component ratios of stainless steel fiber are compared in Fig. 3. For fabric component ratios, see table 1, the primary factor of W10 was absorption, W40 was reflection, and absorption after 1200 MHz. W20 and W30 reflected more electromagnetic waves in low frequency, and absorbed less in high frequency.



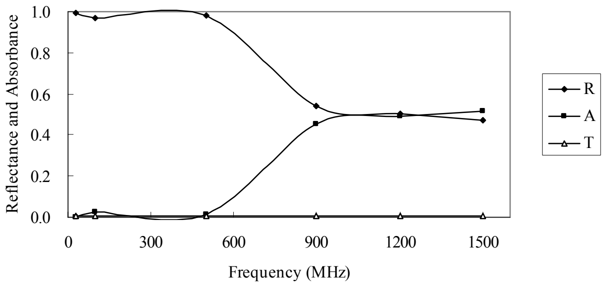
(a)M10



(b) M20



(c) M30



(d) M40

Fig. 4. Reflectance, absorbance and transmittance in meshed fabrics were investigated

M10 provided best absorbance behavior. M20 and M30 absorbed most of the electromagnetic waves after 300 MHz as shown in Fig. 4. For the most part, M40 only reflected electromagnetic waves before 900 MHz, but absorbance and reflectance were half after 900 MHz. As expected, M10, M20, M30 had higher absorption capability. Reflection capability gradually increased with an increase in component ratio of stainless steel fiber and a major factor of EMI SE was reflected for M40.

4. Conclusions

EMI shielding characteristics of conductive fabrics can be divided into reflection, transmission, and absorption behaviors in our studies. It has been shown that when the conductivity and the density of fabrics are higher, the EMI SE is also higher. A decrease in reflectance and an increase in absorbance of stainless steel/polyester fabrics were found at an increased frequency. The variation increased in the reflectance and absorbance of stainless steel/polyester fabrics over 30 MHz to 100 MHz. In this study, the conductivity is the main factor for EMI shielding characteristics of stainless steel/polyester fabrics, so higher conductivity has higher reflectance and lower absorbance.

Acknowledgements

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