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Computation of shielding effectiveness for electromagnetic shielding blended fabric

Abstract. *This study proposes an equivalent metal shield model in order to solve shielding effectiveness (SE) computation of electromagnetic shielding (EMS) blended fabric. The equivalent metal shield consisting of metal fiber is constructed according to the metal fiber content per unit volume of the EMS fabric, and a computation method for the thickness of the equivalent metal shield is given. Then a SE computation of EMS fabric based on the equivalent metal shield model is established. An equivalent coefficient of the SE computation of plain, twill and satin weave fabric is determined by experiments. Results and analyses show that the relative errors of the proposed computations are low and the computations and evaluations are satisfied for the normal EMS blended fabrics.*

Streszczenie. *W artykule przedstawiono sposób modelowania ekranu metalowego, na potrzeby obliczeń numerycznych efektywności ekranowania tkaniny mieszanej, zawierającej włókna metalowe. Wyznaczono współczynnik efektywności ekranowania w zależności od rodzaju zastosowanej tkaniny. Wyniki analiz i obliczeń błędów względnych wykazały, że wyznaczone wielkości są niewielkie i satysfakcjonujące dla typowych tkanin mieszanych. (**Obliczenia skuteczności ekranowania dla ekranu elektromagnetycznego z tkaniny mieszanej**).*

Keywords: computation, equivalent metal shield, electromagnetic shielding blended fabric, modeling, shielding effectiveness
Słowa kluczowe: obliczenia, równoważny ekran metalowy, ekran elektromagnetyczny z tkaniny mieszanej, modelowanie,

Introduction

Electromagnetic shielding (EMS) blended fabric can shield the electromagnetic wave to protect the object from radiation, and consequently it are widely applied in all kinds of fields, such as flexible shield, composite material matrix and EMS clothing [1]. The index of shielding effectiveness (SE) is mainly inspected for the design, manufacture and evaluation of the EMS blended fabric. Therefore, the SE computation of the EMS blended fabric is an important research.

The SE of the EMS blended fabric is completely obtained by experimental testing until now, and no suitable modeling and computation for the SE is available. There are few relative researches about the SE of the EMS blended fabric, existing literatures mainly focus on the model construction of the EMS fabric [2], SE variation analyses [3-4], SE testing method establishment [5-6], SE performance testing [7], and EMS fabric development [8].

Researches about the SE computation of metal shield are more. The computation methods mainly are analytic calculation [9], transmission line method [10], finite difference time domain method [11], moment method [12], and transmission line matrix [13]. However, the SE computation of the metal shield is not suitable for the EMS fabric. The EMS fabric consists of many independent yarns; there are many interstices in the fabric. Moreover, fabric weaves are various and fabric surfaces are rough. The electromagnetic wave can produce conventional angel reflection at the fabric interface and multiple reflections in the fabric. Therefore, we must study the SE computation according to the fabric features.

In this paper, we calculate the metal fiber content per unit volume of the EMS blended fabric according to the fabric structure, and construct an equivalent metal shield model to calculate the thickness. Then we establish the SE computation of the fabric. Finally, the accuracy of the established computation is verified. Results show that this computation model can calculate the SE of normal EMS blended fabric successfully.

Equivalent metal shield model construction

The EMS blended fabric consists of the yarns containing metal fibers. The structure of metal fibers is in a cross arrangement and much hairiness contact each other. It is difficult to calculate the SE of the fabric according to the feature parameters of the metal fiber because of the mess of the microscopic arrangement of the metal fiber. Therefore, we consider the EMS blended fabric as an idea metal shield, as shown in Figure 1. The shield is made from metal fibers and no interstice, its surface is smooth. The metal content and a plain size of the metal shield are consistent with that of the fabric. The thickness of the shield is calculated by the structure parameters and the metal fiber content of original fabric. We call the shield as equivalent metal shield of the EMS blended fabric.

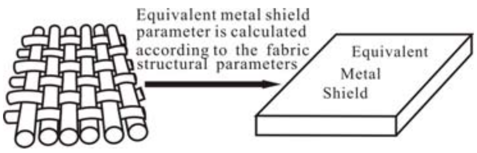

Fig.1. Equivalent metal shield

As can be seen in Figure 1, the equivalent metal shield is a continuous metal shield, and the thickness of the equivalent metal shield is related to the metal fiber content per unit volume of the fabric. Therefore, we obtain the thickness of the equivalent metal shield according to the structure parameters of the fabric.

Assume the warp density of the fabric is D_w (ends/cm), the weft density is D_v (ends/cm), the yarn diameter is d (mm), the metal content of the metal fiber is p, the area of the fabric is $a \times b$ (cm), then the metal content T of all metal fibers in the fabric can be calculated as:

$$T = ab\left(\frac{D_w \times \pi d^2 \times p}{10} + \frac{D_v \times \pi d^2 \times p}{10}\right) \tag{1}$$

Let the size of the equivalent metal shield is $a \times b$, and then the thickness h can be expressed as:

$$h = \frac{T}{a \times b} = \frac{\pi d^2 p}{10}(D_w + D_v) \tag{2}$$

The main shielding ways of an idea metal shield are reflection, multiple reflection and absorption according to the electromagnetic theory [14]. The SE of the fabric can be written as [15]:

$$SE = 168.16 - 10Lg\frac{\mu_r f}{\sigma_r} + 1.31t\sqrt{f\mu_r\sigma_r} \ \ (dB) \tag{3}$$

where t denotes the thickness of idea shield, μ_r refers to the relative magnetic permeability (H/m), σ_r represents the relative conductivity (S/m), f is the frequency (H_z).

The thickness in Equation (3) is the thickness of the equivalent metal shield, so the value of h from Equation (2) is substituted into Equation (3). The SE can be calculated as:

(4) $$SE = 168.16 - 10Lg\frac{\mu_r f}{\sigma_r} + 1.31\frac{\pi d^2 p}{1000}(D_w + D_v)\sqrt{f\mu_r\sigma_r}\,(dB)$$

The equivalent metal shield is an overall metal media according to analyses mentioned above, and the EMS blended fabric consists of many independent cross fibers. The SE values of the two are different. To describe the relation between the SE of the equivalent metal shield and the SE of the EMS blended fabric, we introduce a correction coefficient ε. Therefore, the SE of the EMS blended fabric can be rewritten as:

(5) $$SE = \varepsilon(168.16 - 10Lg\frac{\mu_r f}{\sigma_r}) + 1.31\varepsilon\frac{\pi d^2 p}{1000}(D_w + D_v)\sqrt{f\mu_r\sigma_r}\,(dB)$$

The correction coefficient ε reflects the relation between the SE of the equivalent metal shield and the SE of the EMS blended fabric, and the correction coefficient can be obtained by experiments.

Equivalent coefficient determination

We select a number of EMS blended fabrics with different specifications as experimental samples. The weaves of the samples are plain, twill, and satin. The metal (stainless steel) fiber content of each sample is 15 %. The size of each sample is 30 cm × 30 cm.

We test the SE of each sample using the waveguide tube testing system. The frequency is set as 2 GHz, the distant between the emission source and the sample is 150 cm.

According to experiments, the SE is obtained using the waveguide system, and the coefficient is calculated by Equation (5) (Here μ_r is 500 H/m, σ_r is 0.02 S/m, they are the relative magnetic permeability and relative conductivity of the stainless steel fiber when the frequency is equal to 2 GHz). The average value of the weft and warp density is calculated by: $D_T = (D_w + D_v)/2$, and the total density change is denoted by the average value because the metal fiber content is calculated according to the weft density and the warp density. The variation of the coefficient ε with the total density is illustrated in Figure 2.

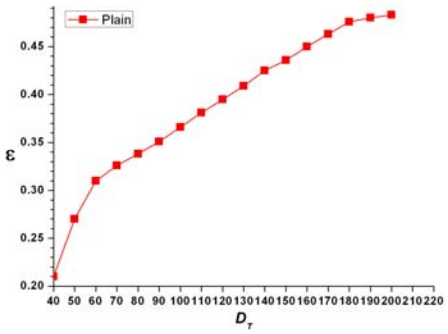

Fig.2. Variation of coefficient ε with the total density

As can be seen in Figure 2, for the plain weave fabric, we can observe that the coefficient ε starts to change when the density is 60, and the variation is near a line. The coefficient ε reaches 0.47 and trends to stable when the density is 180. According to the line slope, the coefficient ε can calculated as:

(6) $$\varepsilon = k(D_T - 60) + 0.31$$

Equation (6) is substituted into Equation (5), then

(7) $$SE_c = (k(\frac{(D_w + D_v)}{2} - 60) + 0.31) \times SE$$

Where, SE is a theoretical value of the equivalent metal shield, SE_c is the SE of the fabric after calculating by the correction coefficient.

In Equation (7), for the plain weave fabric, the original value is 0.31, and the original value of total density is 60. If this equation is applied to any fabrics, let the value of ε is ε_b, the value of the total density is D_b, and then Equation (7) is rewritten as:

(8) $$SE_c = (k(\frac{(D_w + D_v)}{2} - D_b) + \varepsilon_b) \times SE$$

Where k denotes an equivalent coefficient.

According to the proposed methods, the SE values of the fabrics with the plain, twill and satin weaves are tested and noted as SE_c, and the equivalent coefficient, the correction coefficient and the original value of the total density are obtained by Equations（5）-（8）, as listed in Table 1.

Table 1. Equivalent coefficient, original value of correction coefficient, original value of total density of fabric

Fabric type	Plain	Twill	Satin
Equivalent coefficient k (10^{-3})	1.38	1.31	1.23
value of correction coefficient ε_b	0.31	0.30	0.28
Total density D_b	60	66	74

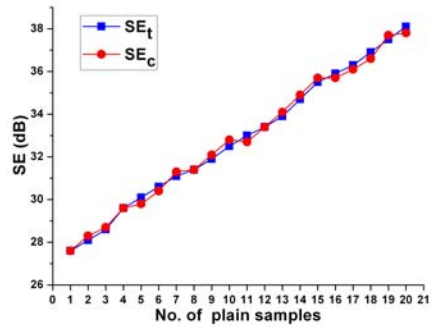

Fig.3. Comparisons between the SE testing results and the SE computation results of the plain weave fabric

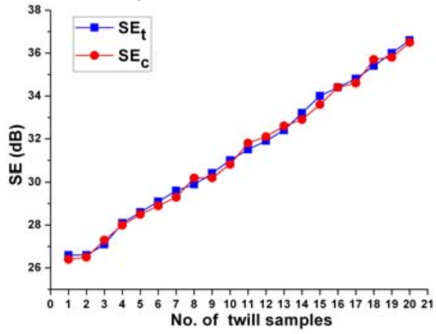

Fig.4. Comparisons between the SE testing results and the SE computation results of the twill weave fabric

Verification and discussion

Twenty arbitrary fabrics with the plain, twill and satin weaves each are selected and their total densities are designed from 70 to 220（ends/10cm）. The structural parameter values listed in Table 1 are substituted into Equation (8) to calculate the SE_c value of the fabrics. The SE_t value of the fabric is tested using the waveguide system. The accuracy of Equation (8) is evaluated by comparing the value of SE_t with the value of SE_c. Figures 3-5 illustrate the SE testing results and the SE computation results of 10 samples each for limited space.

Table 2 presents the relative error between the SE computation value and the SE testing value.

We find that the relative error is low and the computation model of the SE is satisfied when the yarn diameter and the density are reasonable.

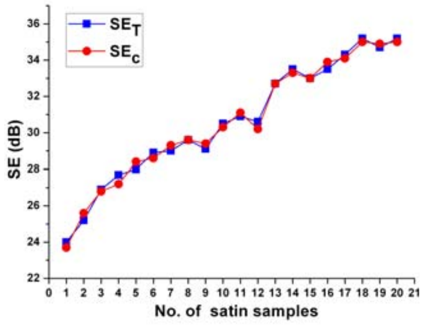

Fig.5. Comparisons between the SE testing results and the SE computation results of the satin weave fabric

Table 2. Relative error between the computation value and the testing value of the SE

Sample weave	Plain	Twill	Satin
Metal fiber content (%)	10-18	10-15	10-15
Yarn diameter (mm)	0.51-0.92	0.51-0.92	0.51-0.92
Fabric density (ends/10cm)	70-210	80-190	80-180
The number of samples	20	20	20
Max relative error	1.9%	2.2%	3.1%
Average Relative error	1.3%	1.6%	2.1%

After experiments and analyses, we conclude that the SE of the fabric is low when the density is lesser than a certain value and it is no variations to follow. The reason is the arrangement between yarns is loose. Therefore, Equation (9) cannot effectively calculate the SE of the EMS blended fabric. When the density is larger than a certain value, the arrangement between yarns is close and the shielding effect will not increase obviously with the increase of density. The computation model also can not accurately calculate the SE because results from Equation (9) are larger than the actual value. Therefore, the yarn diameter range and the density range in Equation (9) are required, as listed in Table 2.

In experimental testing, the emission frequencies are selected in a range (1.8 GHz - 2.6 GHz), and the SE testing values are compared with the SE computation values. The results are in the values range of Table 2. Limited by the experimental equipments, the accuracy of Equation (9) is not verified when the frequencies are less than or larger than the range.

However, according to the analyses for Equation (9), the computation equation includes the frequency parameter, and it is suitable for the metal shield. In the derivation, Equation (3) is the basis of Equation (9). Equation (3) can calculate the SE for idea metal shield, and the accuracy is verified. Therefore, we deduce that Equation (9) should be effective when the frequency exceeds the experimental range. We will verify the deduction in further research.

In the same reason, the computation model is constructed base on idea metal shield, so it is suitable for any metal shield. Equation (9) can apply to the EMS blended fabric with other metal fibers.

Conclusions

1）The model construction for equivalent metal shield is reasonable. The microscope metal fiber with disorder arrangement is simplified to an idea metal shield for analyses. It can lay a foundation for the SE computation of the EMS blended fabric.

2) The computation model can calculate the SE for normal EMS blended fabric, and the computation error is low.

3) The equivalent coefficient, original value of correction coefficient, original value of total density of plain, twill and satin weave fabrics from experimental analyses and derivation are effective and it can calculate the SE of the EMS blended fabric with different weaves.

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