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Influence of Metal Fibre Content of Blended Electromagnetic Shielding Fabric on Shielding Effectiveness Considering Fabric Weave

Abstract
There are few researches reported about the influence of the metal fibre content of blended electromagnetic shielding (EMS) fabric on shielding effectiveness (SE) under different fabric parameters. In order to scientifically describe the metal fibre content of blended EMS fabric considering the fabric structure, in this paper two new indicators of structure metal fibre content (SMFC) and structure equivalent thickness (SET) were constructed according to fabric structure parameters of weft and warp density, yarn density and yarn metal content. A number of experiments were designed and sixteen groups of samples prepared to explore the influence of the two indicators on the SE. Firstly the SMFC and SET of the samples were calculated by the equations of the new indicators. SE values of the samples were then tested by the waveguide method. Finally the relations between the new indicators and the SE were analysed according to experimental results and electromagnetic wave theory. Results show that the SMFC and SET can scientifically describe the metal fibre content of the blended EMS fabric. The SMFC and SET show positive growth along with the SE while other parameters remain unchanged. For the basic weave, SE values are an approximate equivalence as long as the total densities are the same as the yarn density and fibre content of the yarns is the same. As the SMFC is consistent, the more floats, the lower the SE. The research in this paper can provide an important reference for the design, testing and production of blended EMS fabric.

Key words: *fabric blended electromagnetic shielding, fabric structure, metal fibre content, shielding effectiveness, metal fibre influence.*

Introduction

Blended electromagnetic shielding (EMS) fabrics have important applications in the defense, aerospace, industrial, medical, civil and other fields [1]. The principle is that telectromagnetic waves are shielded by adding metal conductive fibre into fabrics [2]. The shielding effect of the blended EMS fabric is evaluated by an indicator of shielding effectiveness (SE). The influence of the metal fibre content on the SE of blended EMS fabric is important as the fabric structure parameters are different [3]. Few researches about the relations between the content of the metal fibre and the SE considering the structure parameters are being reported at present. Related researches are focused on the SE testing method [4, 5], porosity study [6], SE variation [7], the SE of EMS fabric [8], product development [9] and model construction [10]. From an analysis of the fabric structure feature, the content and arrangement of the metal fibre are related to the fabric density, yarn density, metal content of single yarn and the fabric weave. A number of researches about the above parameters are reported [11 - 14]. However, they only discussed the influence of the parameters of density and weave on the SE from the fabric structure, and they did not make acomprehensive comparison between the content of the metal fibre and structure parameters.

In this paper, the influence of the metal content on the SE is important as the structure parameters of the blended EMS fabric are consistent, and the influence of the structure change on the SE are also significant as the metal fibres are consistent. Only these two aspects are discussed, and hence we can display the essence of the shielding effect of EMS fabric, the results of which can provide the basis for the design, production and testing of EMS fabric.

This paper studies the influence of the content of metal fibre on the SE of blended EMS fabric with a changed fabric structure. Firstly we define three parameters to describe the content of the metal fibre. Then we design a number of experiments to group the samples and test the SE according to the principle of different weave structures and same metal fibre contents. Combining the three parameters and the electromagnetic wave theory, we analyze the influence of the content of the metal fibre on the SE when the fabric structures are different, and conclude the analysis results.

Description parameter of metal fibre content considering fabric structure

The content of metal fibre cannot be simply described as a percentage; the fabric structure parameters must also be taken into account. Therefore we propose two indicators to represent the content of the metal fibre considering the fabric structure parameters: the structure metal fibre content (SMFC) - M_C and structure equivalent thickness (SET) - M_T.

The SMFC M_C, in g/cm^2 is the metal fibre content per unit area. The indicator is proposed considering the structure parameters of the weft and warp density of the EMS fabric and the metal fibre content. Suppose D_w and D_v are the weft density and warp density (threads/10cm) of the EMS fabric N_t, in tex the yarn density, P, in %) the metal fibre content in the yarns, and the total length L of the total warp and weft yarns in an area of 1 cm^2 is expressed as:

$$L = \frac{D_v}{10} \times 1 + \frac{D_w}{10} \times 1 \qquad (1)$$

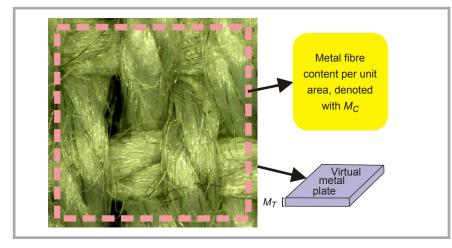The unit of yarn density is converted from g/1000 m to g/1 cm, then combining the metal fibre content, the SMFC per unit area can be obtained:

Figure 1. *Parameters schematic diagram of metal fibre content.*

Figure 2. *Schematic diagram of waveguide testing system.*

Table 1. *Sample grouping, SMFC-M_C and SET-M_T.*

Group number	Warp and weft density	M_C ×10⁻⁴, g/cm²	M_T ×10⁻⁴, cm
1	280 × 236	35.81	4.62
2	340 × 220	38.86	5.02
3	328 × 260	40.80	5.27
4	320 × 300	43.04	5.55
5	380 × 300	47.20	6.09
6	360 × 302	45.90	6.20
7	400 × 340	51.36	6.63
8	420 × 380	55.52	7.16
9	266 × 250	35.80	4.62
10	320 × 240	38.86	5.02
11	288 × 300	40.80	5.27
12	360 × 260	43.04	5.55
13	350 × 330	47.20	6.09
14	344 × 318	45.90	6.20
15	420 × 320	51.36	6.63
16	440 × 360	55.52	7.16

$$M_C = L \times \frac{N_t}{1000 \times 100} \times P$$
$$= \frac{D_w + D_v}{10^6} \times N_t \times P \qquad (2)$$

and next the SET M_T is the thickness of a virtual pressed equivalent metal plate with a size of 1 × 1 cm according to the metal fibre content. The SE of the equivalent metal plate is consistent with the

original EMS fabric. The SET can intuitively evaluate the SE of the EMS fabric in another way. The M_T can be denoted as:

$$M_T = \frac{M_C}{\rho} \qquad (3)$$

where, ρ in g/cm³ is the volume density of the metal fibre.

Figure 1 gives the meaning of above parameters discussed.

Experimental method

We select 21ˢ blended yarns (25% stainless steel fibre, 35% cotton, 40% polyester (produced by Shanghai Angel Textile Company of China) as weft and warp yarns to manufacture samples with a plain weave, twill weave and satin weave using a SGA598 sample loom (produced by Jiangyin Tong Yuan Textile Company of China), and test the sample densities using a Y511B fabric density testing instrument (produced by Ningbo Textile Instrument Factory of China). The samples are divided into 16 groups according to the densities. Each group contains three plain weave, twill weave and satin weave samples with the same densities. The SMFC M_C of each sample was calculated, and details of which are listed in *Table 1*.

The fabrics manufactured listed in *Table 1* are reproduced as test samples with a size of 65 × 110 mm, and the SE values are tested using the waveguide testing system (produced by Xi'an University of Technology of China), as shown in *Figure 2* [15]. The frequency ranges are from 2200 MHz to 2650 MHz. The testing method is in accordance with the American SE testing standard ASTM D4935.

The waveguide testing system in general consists of a network analyzer, signal emission sensor, signal receiving sensor and a waveguide. In this system, the signal is launched by the emission sensor, next after passing the sample (shielding fabric) is received by the receiving sensor and transmitted to the network analyzer. Finally, *SE* of the fabric is calculated as [15]:

$$SE = 20 \lg \frac{E_0}{E_1}, \qquad (4)$$

where, E_0 is the electric field intensity of one frequency value without the fabric shielding, E_1 is the electric field intensity of one frequency value with the fabric.

Results and discussion

Relationship between SMFC and SE

Figure 3 presents the variation in the SE of each sample listed in *Table 1*. We only list the *SE* variation at 2400 MHz frequency (f = 2400 MHz) due to the limited space. The *SE* variation in other frequencies is also in accordance with the rule shown in *Figure 3*. *Figures 4* and *5* are constructed in the same way.

From **Figure 3**, it is noticed that the *SE* of the EMS fabric is directly proportional to the SMFC, such as from Group 1 to Group 8 and from Group 9 to Group 16. Suppose is the proportional coefficient, then:

$$SE \approx \lambda M_C \qquad (5)$$

From **Equation 2**, it is observed that $D_w + D_v$ is the ratio of the M_C. Therefore, *SE* is directly proportional to $D_w + D_v$.

Let

$$D_t = D_w + D_v \qquad (6)$$

then:

$$SE \approx \mu D_t \qquad (7)$$

where, D_t is the total density of the EMS fabric, μ is the proportional coefficient of the total density, which can be obtained by experiment.

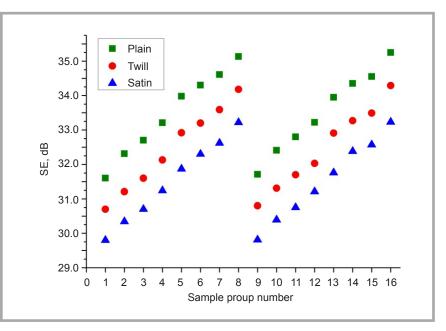From the analysis presented above, the SE of the EMS fabric can be calculated

Figure 3. *SE variation of each sample listed in* **Table 1** *with a change in SMFC (f = 2400 MHz).*
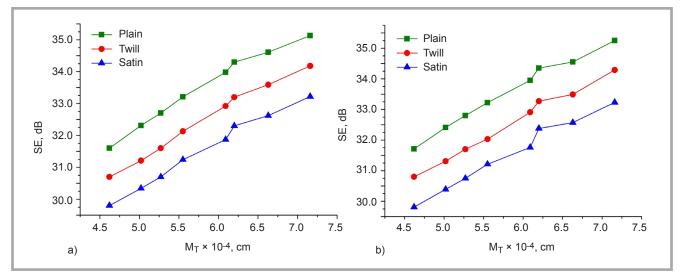

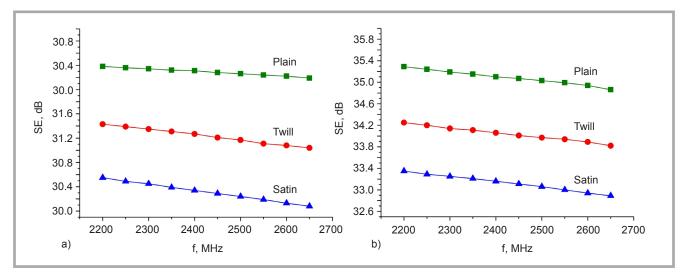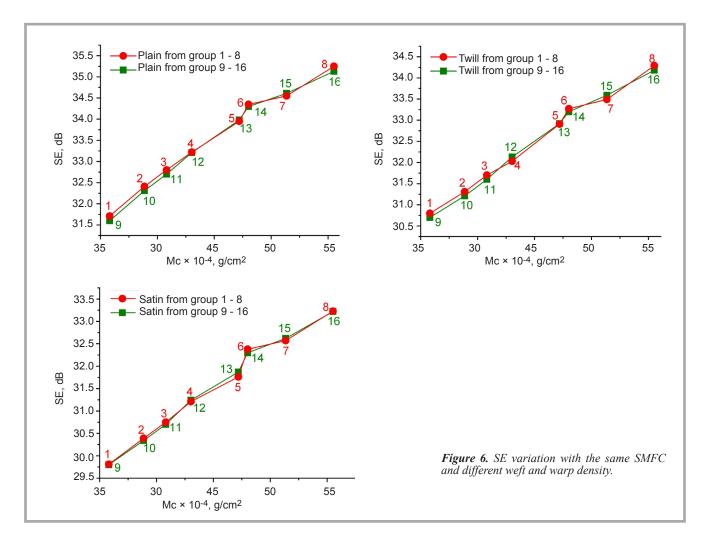**Figure 4.** *Variation of SE of each sample with change of SET (f = 2400 MHz); a) from group 1 to 8 and b) from group 9 to 16..*

Figure 5. *Influence of SE with frequency variation; a) Mc = 38.86 × 10-4 g/cm2, and b) Mc = 55.52 × 10-4 g/cm2.*

Figure 6. SE variation with the same SMFC and different weft and warp density.

by *Equations 6 - 7* as long as the warp density and weft density are determined. Therefore the efficiency of the design, production and testing can be improved, providing an important guidance for the production of blended EMS fabric.

Influence of SET on SE

The SET is an indicator which reflects the metal fibre content considering the fabric structure. From *Equation 2*, it is noticed that the SET has a linear relationship with SMFC. Therefore we can obtain:

$$SE \approx \lambda' M_T \qquad (8)$$

where, λ' is the proportionality coefficient between M_T and SE.

Table 2. Average correlation coefficient R_2 of SE and frequency of samples with different weaves shown in **Figure 5**.

	Figure 5.a	Figure 5.b
Plain	0.013364	0.014523
Twill	0.012929	0.014089
Satin	0.012549	0.013712

Equation 8 shows that a large SET is caused by a high metal fibre content per unit area for the same structure parameter, and the shielding of the fabric is high. *Figure 4* illustrates the variation in the *SE* with a change in the SET.

From *Figures 3* and *4*, it is observed that the *SE* values of the fabrics with different weaves are various when the SET and SMFC are the same. The *SE* value of the plain weave fabric is the largest, followed by the twill weave fabric, and the *SE* value of the satin weave fabric is the lowest. We find the results are caused by the floats of the EMS fabric. The weft and warp weave points of the plain weave fabric appear alternately in any direction, and there is no float. Two or more weft and warp weave points continuously appear in the twill weave fabric, and floats occur. In satin weave fabric, many weft and warp weave points continuously appear, and the floats are longer than those of the twill weave fabric. The yarns could not close each other, and interstices are produced, producing the loss of the elec-

tromagnetic wave [16]. Therefore the SE of the fabric with more floats is lower than the SE with no float.

Influence of frequency on SE for consistent structure parameters

The frequencies are chosen from 2200 to 2650 MHz according to the waveguide system, and the *SE* is tested once every 50 MHz. Experiments show that the *SE* values decrease with an increase in the frequency in spite of the fabric weaves during the whole frequency range. *Figure 5* illustrates the trend of *SE* with a change in the frequency. *Table 2* lists the correlation factor R_2 of *SE* and frequency of the fabrics with different weaves. The R_2 is calculated as:

$$R_2 \approx \frac{SE}{f} \qquad (9)$$

In fact, the magnetic permeability and electrical conductivity of the stainless steel fibre are various with a change in the frequency [17]. In a certain frequency range, the magnetic permeability of the stainless steel fibre decreases and the electrical conductivity increases, result-

ing in a *SE* increases. In another frequency range, the *SE* decreases as the magnetic permeability of the stainless steel fibre increases and the electrical conductivity decreases. Otherwise the properties of the stainless steel fibre are different in the far and near electromagnetic field, influencing the *SE* change [18]. Therefore *SE* variation with a change in frequency shown in *Figure 5* is only limited by the testing method and frequency ranges proposed in this paper. The *SE* variation with a change in the frequency in a wider range will be studied in further research.

Influence of weft and warp density on SE with consistent structure parameters

Figure 6 shows the *SE* variation of the samples listed in *Table 1* for the same SMFC and different weft and warp density.

From *Figure 6*, it is interesting to note that the SE is consistent with a change in the weft and warp density as long as the total density is consistent when the yarn density and metal content is consistent for a basic weave fabric. Let the warp density, weft density, total density and *SE* of a sample be D'_v, D'_w, D'_t and SE', the warp density, weft density, total density and SE of another sample D''_v, D''_w, D''_t and SE'' then

$$D'_t = D'_v + D'_w, \ D''_t = D''_v + D''_w \quad (10)$$

If

$$(D'_t = D''_t) \text{ and } (N'_t = N''_t) \text{ and } (P' = P'') \quad (11)$$

Then

$$SE' \approx SE'' \quad (12)$$

where, N'_t and N''_t are the yarn density of the two fabrics, *P* in % is the metal fibre content of the yarns.

As shown from Group 1 to 8 and from Group 2 to 10 in Figure 6, we consider that the phenomenon is caused by the fabric hairiness and the SMFC. When the yarn density and the total density are consistent, the total number of yarns per unit area is not changed, thus the M_C is also unchanged. Owing to the hairiness of the fabric, the fabric is connected into a conductor at a certain degree, and the influence of different interstices produced by different densities is eliminated, making the SE values of the fabric the same. The results can provide a reference for the design and evaluation of blended EMS fabric.

■ Conclusions

1) Considering the fabric structure, the metal fibre content can be scientifically denoted by the SMFC and SET .

2) The SMFC and the SET are positively and linearly correlated to the *SE* when other parameters are unchanged.

3) In general, *SE* is proportional or inversely proportional to the frequency, depending on the frequency range chosen. For the frequency range used in this work, the SE values are almost inversely proportional to the frequency.

4) For basic weaves, the *SE* of the blended EMS fabric are approximately equal as long as the total densities are the same as the yarn density and the fibre content of the yarn is consistent.

5) As the SMFC are consistent, the more the floats of the basic weave fabric, the lower the SE values. Otherwise the fewer the floats, the higher the *SE* values.

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