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Experimental Studies on the Dielectric Behaviour of Polyester Woven Fabrics

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Abstract
In this paper, the influence of fabric structure, weft density, end spacing and yarn fineness on the dielectric constant of polyester woven fabrics was studied. The results show that at low frequencies, the dielectric constant of fabric was clearly affected by the processing parameters; when the organisation of the fabric is plain i.e. the warp density is 140/10 cm, weft density 140/10 cm and yarn linear density 32 tex, the absorbing performance of polyester woven fabrics is at its best. At higher frequencies, the effect of the varying parameters on the dielectric constant of the fabrics can be neglected. Polyester woven fabrics have better EM absorbing properties for these parameters. This study offers a new theoretical basis for the development of EM absorptive fabrics.

Key words: *polyester woven fabric, structure, weft density, end spacing, yarn linear density, dielectric constant, absorbing performance.*

Introduction

With the increasing environmental concern for microwave irradiation and stealth technology for military platforms, microwave absorbing materials have attracted much attention [1 - 5]. Microwave absorptive fabrics are widely studied not only in the military field for stealth technology, but also in civil aspects to avoid serious pollution of EM radiation from a range of electronic apparatuses [6 - 12]. In recent years, the properties of fabrics and ones coated with absorbers have been investigated [13 - 15].

The microwave absorbing properties of fabrics can be evaluated by their dielectric constant [16, 17]. The dielectric constant is a function of the frequency of the external electric field, with the real part being representative of the microwave absorbing material's degree of polarisation under an applied electric field; the greater its value, the stronger the polarising ability of the material [18 - 21]. The imaginary part on behalf of the energy loss is caused by a rearrangement of the material's dipole moment under an applied electric field; the greater its value, the greater the loss of the ability of electromagnetic waves. The loss tangent is representative of the microwave absorbing attenuation ability; the higher the value, the better the microwave absorbing properties [22 - 26].

Woven fabric samples used in the experiments were made by Tianjin Lunda Electrical and Mechanical Technology Development Co., Ltd's automatic rapier loom, which can precisely control the weft density during the weaving process. Automatic weaving can avoid the uneven tension and errors caused by manual beat-up on a semi-automatic loom. The fabric weaving process includes four steps: warping - across heald - reeding - reaving. In this paper, polyester woven fabrics with absorptive properties and low-cost production were studied. In order to study the effect of the process parameters (fabric structure, weft density, end spacing and yarn linear density) on the dielectric constant of polyester woven fabrics, a series of different samples were woven using the single-factor test method. The aim was to produce polyester woven fabric with the best wave absorption performance.

Experimental procedure

Materials and instruments

The starting material was a partially oriented multifilament polyester yarn of 32, 45 and 59 tex. Polyester yarn used for this work was provided by YOUNGOR Co., Ltd. (Zhejiang, China). Woven fabric samples were produced by Tianjin Lunda Electrical and Mechanical Technology Development Co., Ltd on an automatic rapier loom. The BDS50 dielectric constant dielectric spectrometer used was produced by Novocontrol Experimental Instrument Co., Ltd (Germany).

Measurement of the dielectric constant

In accordance with SJ20512-1995, the dielectric constant was tested on a BDS50 dielectric constant dielectric spectrometer using the second electrode sheet (diameter R = 20 mm) at constant temperature (20 - 22 °C) and humidity (64 - 66% RH) for testing.

Results and discussion

Impact of the fabric structure on the dielectric constant of the fabric

In order to explore the effects of different organisational structures on the dielectric constant of polyester woven fabrics, three different fabric structures were woven on a rapier loom. The sample specifications are shown in ***Table 1*** (see page 68), and the fabric structures in ***Figure 1.***

According to the characteristics of polyester woven fabric material, the fabric can be viewed as a hybrid of fabric incorporating air. The dielectric constant of air is approximately 1, and that of the fab-

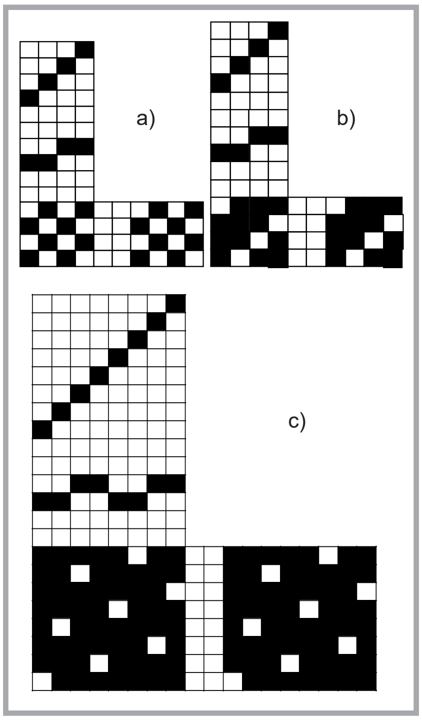


Figure 1. Different organizational fabric structures; a) plain structure, b) 3/1 twill machine structure, c) 8/3 satin machine structure.

ric can be affected by the air. The gap structure and fabric interwoven point can change the propagation of electromagnetic waves within the material line, and the incident electromagnetic wave inside the material has the biggest loss due to a series of scattering and reflection absorption processes. The dielectric constant of textile material is a function of the field frequency. Data obtained by testing three structures of fabric with a varying frequency dielectric constant were analysed and compared. ***Figure 2*** and ***Figure 4*** show that at a lower frequency ($f < 10^5$ Hz), the fabric structure has some influence on the dielectric constant. The dielectric constant's real part, imaginary part, and loss tangent for plain fabric are all larger, hence it has stronger polarisation capability and loss capacity compared with the other two organisations, which may be because plain fabric has the most intertwined points, and thus is less affected by the air. When the frequency of the external electric field is increased, the dielectric polarisation of the material is reduced, the ε value decreased and the loss capacity is reduced. The real and imaginary parts for the three fabrics were approximately coincident at higher frequencies; the influence of the fabric structure on the dielectric constant at high frequency can be neglected.

Table 1. *Sample specification for the different organizational fabric structures.*

Number	Organization	Weft density, line/10 cm	End space, line/10 cm	Yarn linear density, tex
1 2 3	Plain Twill 3/1 Satin 8/3	140	200	59

Table 2. *Sample specification for the different weft density fabrics.*

Number	Organization	Weft density, line/10 cm	End space, line/10 cm	Yarn linear density, tex
1 2 3 4 5	Plain	80 110 140 170 200	200	59

Table 3. *Sample specification for the different warp density fabrics.*

Number	Organization	Weft density, line/10 cm	End space, line/10 cm	Yarn linear density, tex
1 2 3 4 5	Plain	140	140 180 200 210 240	59

Table 4. *Sample specification for different yarn linear density.*

Number	Organization	Weft density, line/10 cm	End space, line/10 cm	Yarn linear density, tex
1 2 3	Plain	140	140	59 45 32

Impact of fabric weft density on the dielectric constant

In order to explore the influence of the fabric weft density on the dielectric constant, five different weft density fabrics were woven on a rapier loom. The sample specifications are shown in ***Table 2***.

Figure 5 and ***Figure 6*** show the real and imaginary parts of the dielectric constant for the five fabric samples. At low frequencies ($f < 10^4$ Hz), the fabric weft density has a greater impact on the dielectric constant. For these five fabrics, the fabric with a weft density of 140/10 cm has the maximum dielectric constant, which may be because when a fabric has the same yarn linear density, structure and warp density, and when the weft density increases, the gap between the weft becomes smaller, consequently there is less air in the fabric and the dielectric constant of the fabric is increased. When the weft density reaches a certain point, the weft is almost fused and the dielectric constant of the fabric is reduced. When frequencies are higher than 10^4 Hz, the impact of the fabric weft density on the dielectric constant can be neglected.

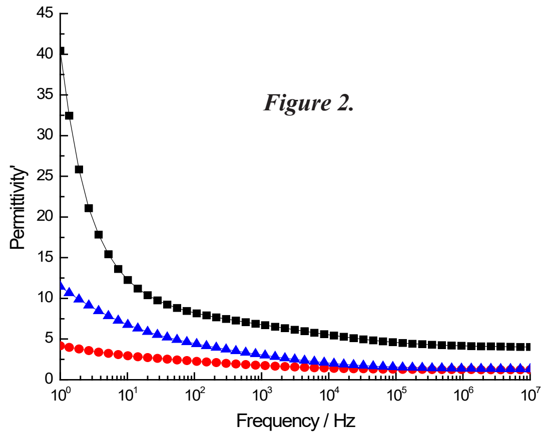
Impact of fabric warp density on the dielectric constant

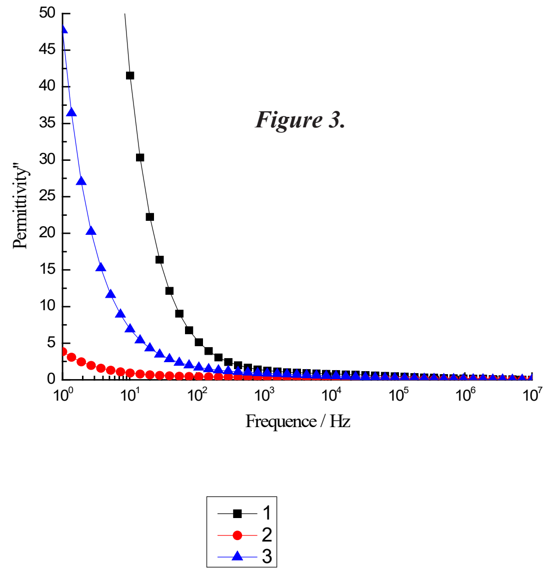
In order to explore the impact of warp density on the dielectric constant, five different fabrics were woven on a rapier loom. Their sample specifications are shown in ***Table 3***.

Figures 8 to ***10*** (see page 70) show the trend of the dielectric constant and loss tangent of different warp densities with changing frequency. At low frequencies ($f < 10^3$ Hz), the influence of the fabric warp density on the dielectric constant is large, which can be seen from the figure to be close to 140/10 cm; the dielectric constant is at its largest; both the loss ability and polarisation capability are stronger, and the absorbing performance is better. With an increase in warp density, the dielectric constant decreases, and hence the loss tangent value decreases. This is probably because when the warp density is large, when it is almost bonded together to form exchange pathways, the absorbing performance decreases. At high frequencies, the impact of the yarn warp density on the dielectric constant is small.

Impact of the dielectric constant on yarn linear density

In order to explore the effects of yarn linear density on the dielectric constant,





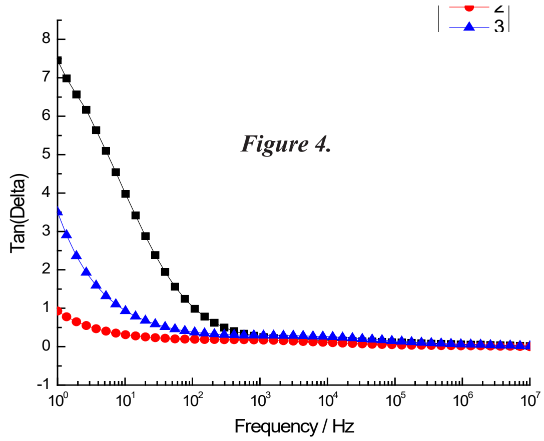
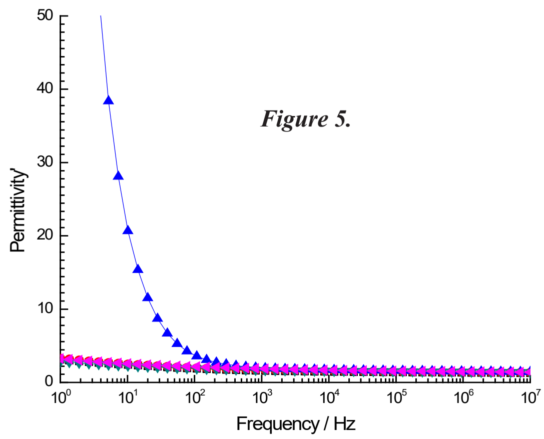
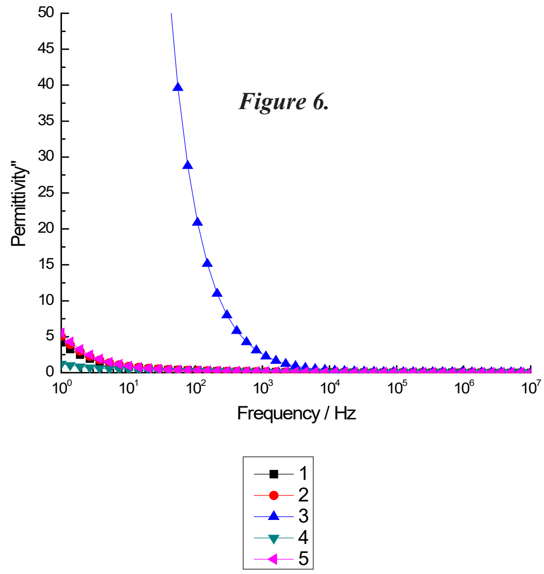


Figure 2. Impact of fabric structure on the real part of the dielectric constant.

Figure 3. Impact of fabric structure on the imaginary part of the dielectric constant.

Figure 4. Impact of fabric structure on the loss tangent of the dielectric constant.





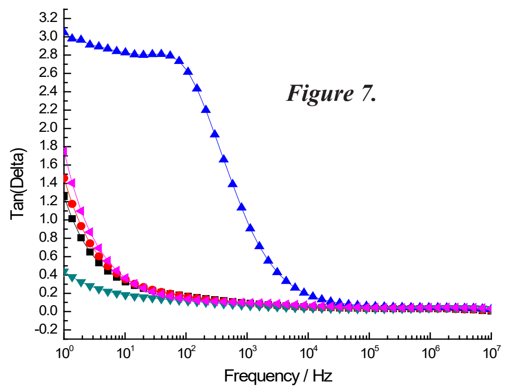
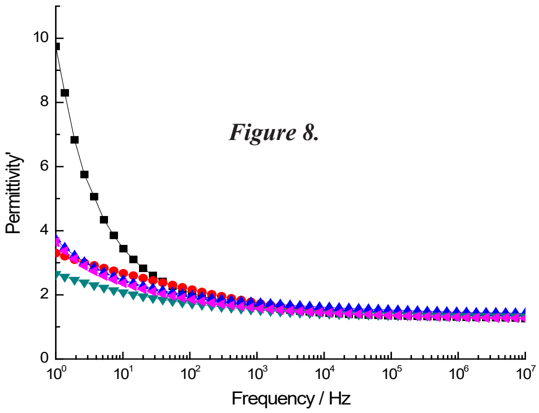
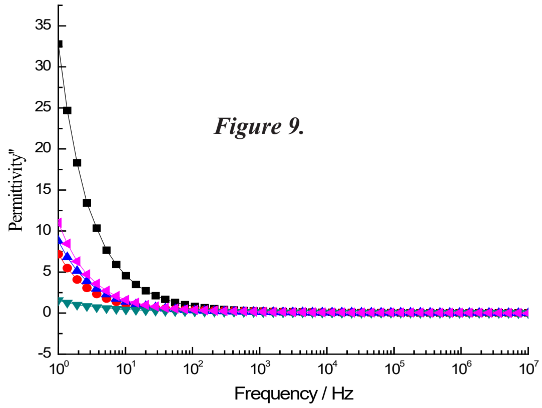


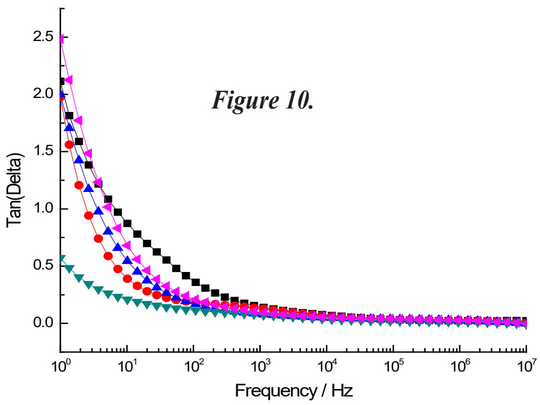
Figure 5. Impact of weft density on the real part of the dielectric constant.

Figure 6. Impact of weft density on the imaginary part of the dielectric constant.

Figure 7. Impact of weft density on the loss tangent of the dielectric constant.







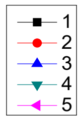
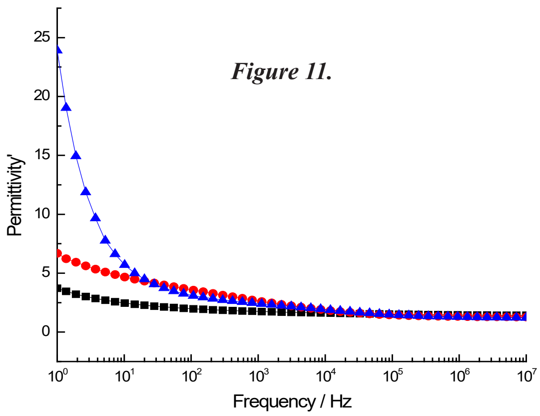
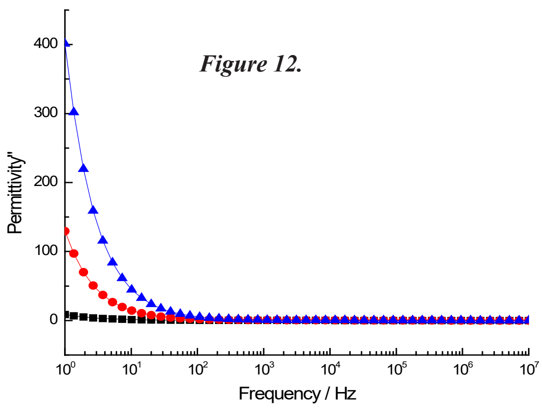


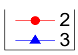
Figure 8. Impact of warp density on the real part of the dielectric constant

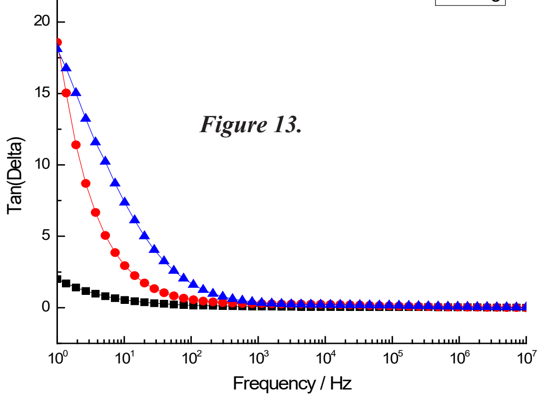
Figure 9. Impact of warp density on the imaginary part of the dielectric constant

Figure 10. Impact of warp density on the loss tangent of the dielectric constant.









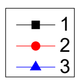


Figure 11. Impact of yarn linear density on the real part of the dielectric constant.

Figure 12. Impact of yarn linear density on the imaginary part of the dielectric constant.

Figure 13. Impact of yarn linear density on the loss tangent of the dielectric constant.

a series of fabrics was woven on a rapier loom. The sample specifications are shown in ***Table 4*** (see page 68).

Figures 11 to ***13*** show the electromagnetic parameter curves for various yarn linear density. At low frequency (f <10^3 Hz), the influence of yarn linear density on the dielectric constant is large, and the dielectric constant is at its maximum for a fine yarn - 32 tex. The finer the yarn is, the better the EM absorbing properties obtained. This is probably because, when the fabric structure, weft density and warp density remain unchanged, the thicker the yarn, then the bigger the weaving friction is between yarns and thus the hairiness. The fabric yarns in close proximity to each other bond together to form a communication path, which decreases the dielectric constant. At higher frequencies, the yarn linear density has almost no effect on the dielectric constant.

Conclusions

1) At a lower frequency (f <10^5 Hz), the real part's dielectric constant, imaginary part and the loss tangent for the plain fabric are all larger, and it has better EM absorbing properties compared with the 3/1 twill machine structure and 8/3 satin machine structure.
2) At low frequencies (f <10^4 Hz), the fabric weft density and warp density have a greater impact on the dielectric constant. When the warp density is 140/10 cm and weft density 140/10 cm, the absorbing performance of polyester woven fabrics is at its best. When frequencies are higher than 10^4 Hz, the impact of the fabric weft density and warp density on the dielectric constant can be neglected.
3) At low frequency (f < 10^3 Hz), the influence of yarn linear density on the dielectric constant is large, and the dielectric constant is at its maximum for a fine yarn - 32 tex.
4) This study offers a new theoretical basis for the development of EM absorptive fabrics.

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