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Influence of the Yarn Fineness and Stitch Length of Polyester Knitted Fabric on the Dielectric Constant

DOI: 10.5604/01.3001.0013.4469

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Abstract
The influence of the yarn fineness and stitch length of polyester knitted fabrics on the dielectric constant was investigated by the single factor test method. As a result of the investigation, polyester knitted fabric parameters were chosen so as to obtain a polyester knitted fabric with the maximum real part and imaginary part of the dielectric constant. The results show that when the yarn fineness is 59 tex and the mark of the stitch length is 75, the polyester knitted fabric displayed the maximum real part and imaginary part of the dielectric constant. Finally, the polyester knitted fabric with these parameters had good microwave absorbing properties.

Key words: *polyester knitted fabric, yarn fineness, stitch length, dielectric constant, absorbing property.*

Introduction

Textiles as an electromagnetic wave propagation medium have not been widely studied, and although they are soft, low cost and exhibit good wearability, they do not have satisfactory electromagnetic properties [1-3]. In recent years, with the rapid development of conductive polymers and metalised fabric processing technology, the conductive properties of textiles have improved, resulting in a series of electromagnetic textiles [4-6]. Metal fabrics such as stainless steel fabric, copper mesh fabric, and metallised fabrics such as those subject to chemical plating and magnetron sputtering are known [7-9]. The conductive mechanism for conductive polymers has been established, and a variety of polymerisation technologies for conductive polymers such as polypyrrole (PPy), polythiophene (PTh), and polyaniline (PANI), which can be applied to ordinary fibres or fabric surfaces, have been widely studied; they benefit from the light weight, large area deposition and adjustable conductivity, and have broad application prospects [10-13].

The dielectric constant is an important parameter influencing the electromagnetic properties of textiles. The complex permittivity of fabric plays a fundamental role in inhibiting the propagation of electromagnetic waves. The permittivity has direct relevance to such applications as electromagnetic shielding and radar absorbing fabrics, and the shielding effectiveness or return loss of fabric is directly related to the material chemistry and thickness [14-17]. More precisely, the real part of the complex permittivity shows the ability of the fabric to store charge, and the imaginary part exhibits the energy loss in the dielectric relaxation [18-20]. For electromagnetic propagation calculations of a fabric structure over a wide frequency range, modelling the electrical properties of fabric closer to the experimental measurement is deemed advisable.

In this paper, the influence of the yarn fineness and stitch length of polyester knitted fabrics on the dielectric constant were investigated by the single factor test method. The samples that were used, with different yarn fineness and stitch lengths, were fabricated with an LXC-253SC computerised flat knitting machine.

Experimental procedure

Materials and instruments

Polyester yarn used for this work was provided by the YOUNGOR Co., Ltd. (Zhejiang, China). The LXC-253SC computerised flat knitting machine was made by Jinlong Machinery Co., Ltd. (Jiangsu, China). The BDS50 permittivity dielectric spectrometer was made by Novocontrol Technologies & Co., Ltd. (Germany).

Measurement of the dielectric constant

Experimental procedure

Permittivity measurements were taken twice for each sample in two directions

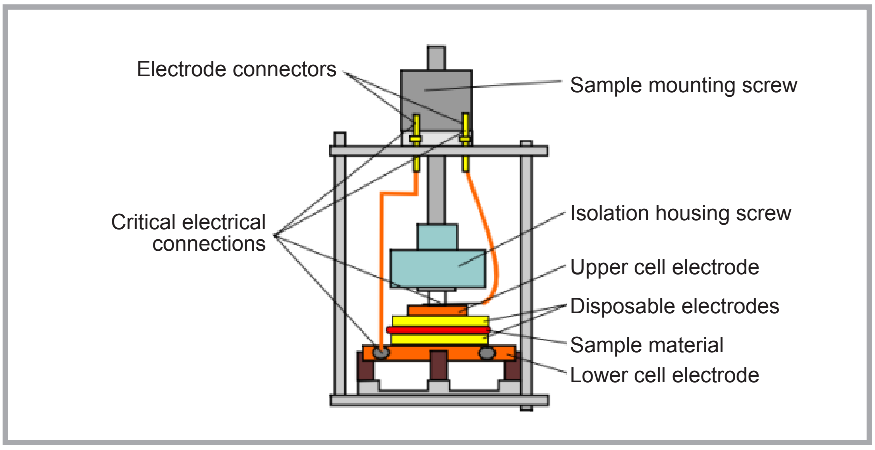

Figure 1. *Sample holder.*

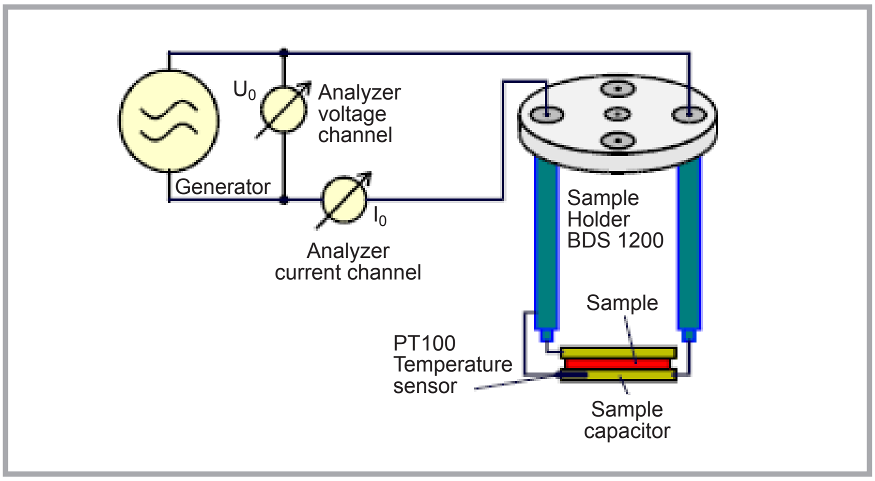

***Figure 2.** Measuring principle of the complex permittivity of the fabric.*

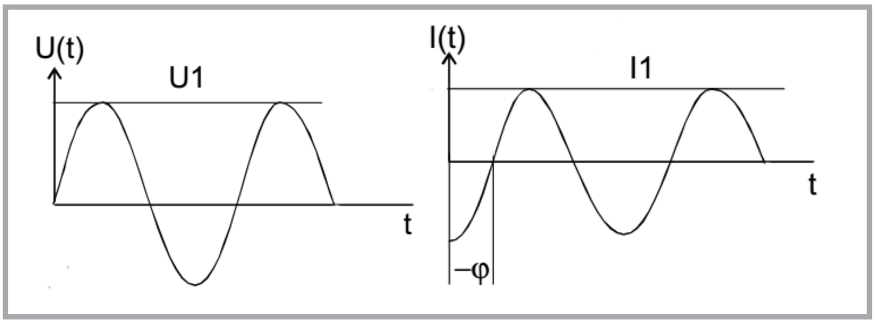

***Figure 3.** Phase difference between the voltage and current.*

according to the fabric direction, taking the total number of tests to 49 observations, following a logarithmic law between 1 Hz and 10 MHz. The sample holder is shown in ***Figure 1***, and measurements were conducted at 20 ± 1 °C and at a humidity of 65 ± 2%.

Extraction of permittivity

An Alpha-A High Performance Frequency Analyzer (purchased from Novocontrol Technologies Corp., German) was used to measuring the complex permittivity of the fabric. This instrument measurement is based on the principle of the capacitive method of material permittivity and impedance, shown in ***Figure 2***.

During the material permittivity and impedance measurement, the voltage U_1 is at a certain frequency $\omega/2\pi$, and the U_1 causing current I_1 is at the same frequency. Moreover, because of the sample, the phase angle φ is between the voltage and current, shown in ***Figure 3***.

***Table 1.** Process parameters for different yarn fineness of polyester knitted fabrics.*

Number	Fabric structure	Yarn fineness, tex	Mark of stitch length
1	2 + 2 rib	32	75
2	2 + 2 rib	45	75
3	2 + 2 rib	59	75

***Table 2.** Process parameters for different stitch lengths of polyester knitted fabric.*

Number	Fabric structure	Yarn fineness, tex	Mark of stitch length
1	2 + 2 rib	59	55
2	2 + 2 rib	59	60
3	2 + 2 rib	59	65
4	2 + 2 rib	59	70
5	2 + 2 rib	59	75
6	2 + 2 rib	59	80
7	2 + 2 rib	59	85

The electromagnetic properties of the sample material and geometric structure will determine the voltage U_1, current I_1 and phase angle φ.This can be expressed as follows in the plural:

$$u(t) = U_1 \cos(\omega t) = \mathrm{Re}(U^* e^{i\omega t})$$

$$i(t) = I_1 \cos(\omega t + \varphi) = \mathrm{Re}(I^* e^{i\omega t})$$

Where

$$U^* = U' + iU'', \; U' = U_1,$$

$$I^* = I' + iI'', \; I' = I_1 \cos(\varphi), \; I'' = I_1 \sin(\varphi)$$

For the linear electromagnetic response of the sample, the characteristic impedance of the sample is obtained with the complex permittivity in ***Equations (1)*** and ***(2)***:

$$Z^* = Z' + iZ'' = U^* / I^* \qquad (1)$$

$$\varepsilon^*(\omega) = \varepsilon' - i\varepsilon'' = \frac{-i}{\omega Z^*(\omega)} \frac{1}{C_0} \qquad (2)$$

Results and discussion

The influence of the yarn fineness of polyester knitted fabric on the dielectric constant

In order to probe the influence of the different yarn fineness of polyester knitted fabrics on the dielectric constant, knitted fabrics with three different yarn fineness were used, fabricated using a computerised flat knitting machine at 12 GG; their process parameters are shown in ***Table 1***.

The fabric samples prepared were measured, and curves for the dielectric constant for the real part and imaginary part are shown in ***Figure 4*** and ***Figure 5***, respectively:

Figure 4 and ***Figure 5*** show that at a low frequency, f < 10^5 Hz, sample 3 displays the greatest real part and imaginary part of the dielectric constant. The real part of knitted fabric that was obtained with a yarn fineness of 59 tex was 4.06, the imaginary part – 1.67, and the loss tangent was 0.46 when the external electric field frequency was 1.13×10^3 Hz. At a low frequency band, the real part and imaginary part of knitted fabrics with yarn finenesses of 59 tex, 32 tex and 45 tex descend in order. With increasing yarn fineness, the real part and imaginary part of the dielectric constant tend to decrease initially before then increasing

According to $\delta = 1/d$ (3)

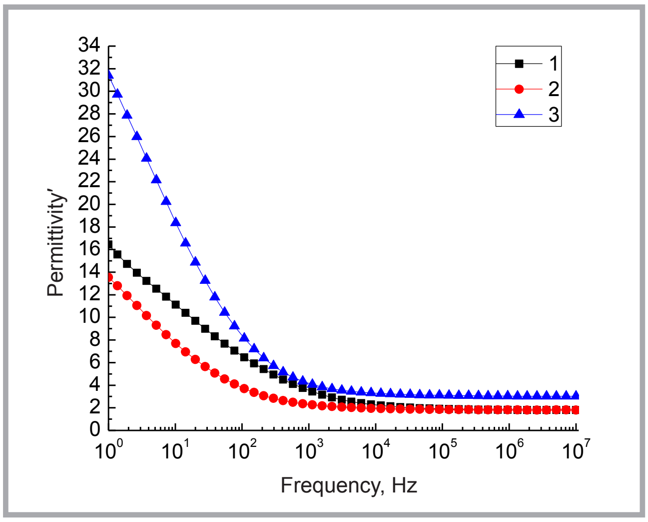

Figure 4. Influence of yarn fineness on the real part of the dielectric constant.

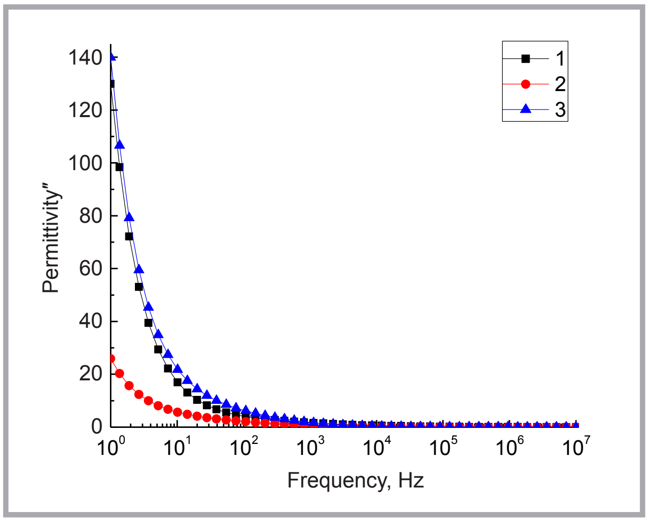

Figure 5. Influence of yarn fineness on the imaginary part of the dielectric constant.

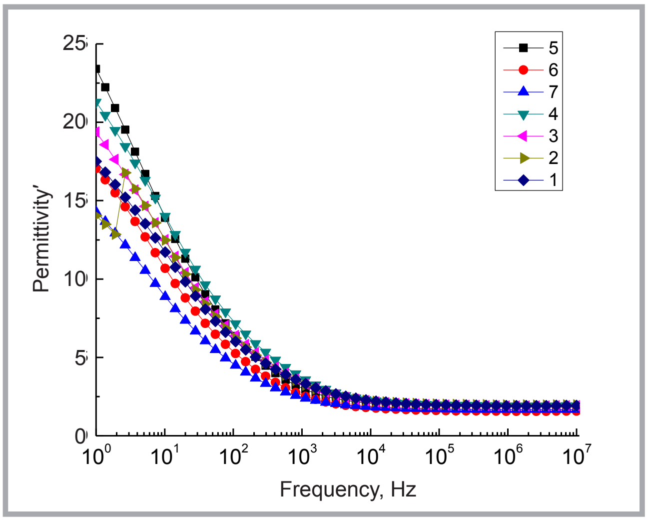

Figure 6. Influence of stitch length on the real part of the dielectric constant.

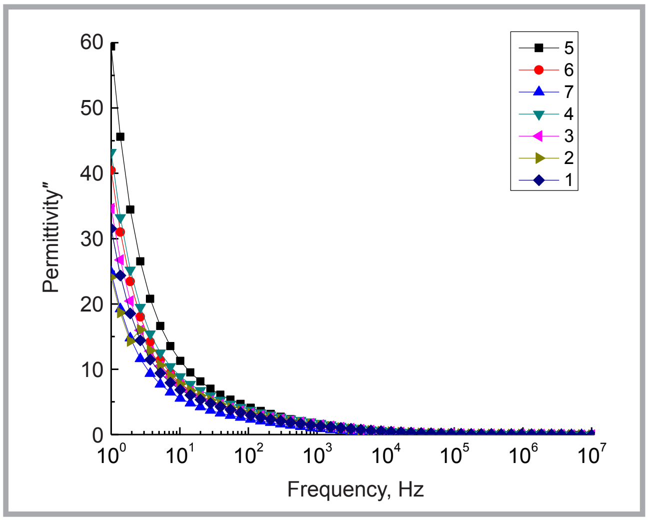

Figure 7. Influence of stitch length on the imaginary part of the dielectric constant.

where:
δ – not filled coefficient,
l – stitch length,
d – yarn diameter,

when the fabric structure and stitch length are constant, then the thicker the yarn the smaller the not filled coefficient of the knitted fabric i.e. the knitted fabric is more dense. Therefore, when the fabric density is increased within a certain range, then the dielectric constant of the fabric can be improved.

A possible explanation for this conclusion is that the gap between the yarns is very little or there is no gap. When there is an increase in the density of the fabric over a certain range, the entire yarn aggregates become an AC path, making the dielectric constant of the fabric decrease.

The influence of the stitch length of polyester knitted fabric on the dielectric constant

In order to probe the influence of different stitch lengths of polyester knitted fabric on the dielectric constant, knitted fabrics with different stitch lengths were fabricated using a computerised flat knitting machine at 12 GG, the process parameters of which are shown in ***Table 2***.

Figure 6 shows that at a low frequency ($f < 10^5$ Hz), the real part of the dielectric constant for polyester knitted fabrics whose mark of stitch lengths are 75, 70, 65, 60, 55, 80, 85 are in descending order. The real part of the dielectric constant decreased with an increase in the stitch length between 55 and 85, and it increased with an increase in the stitch length between 55 and 75. In the high frequency range, the real part curves for polyester knitted fabrics with all seven different stitch lengths approximately overlap, and the impact of the stitch length on the dielectric constant can be ignored.

Figure 7 shows that at low frequency ($f < 10^5$ Hz), the largest imaginary part of the dielectric constant was shown by the polyester knitted fabric whose mark of the stitch length was 75. At a high frequency, the imaginary part curves for all seven different stitch lengths overlap, and their value was approximately 0; thus the impact of the stitch length on the dielectric constant can be ignored.

Figure 8 shows that at low frequency ($f < 10^5$ Hz), the loss tangents for the polyester knitted fabrics were in descending order for marks of the stitch length of

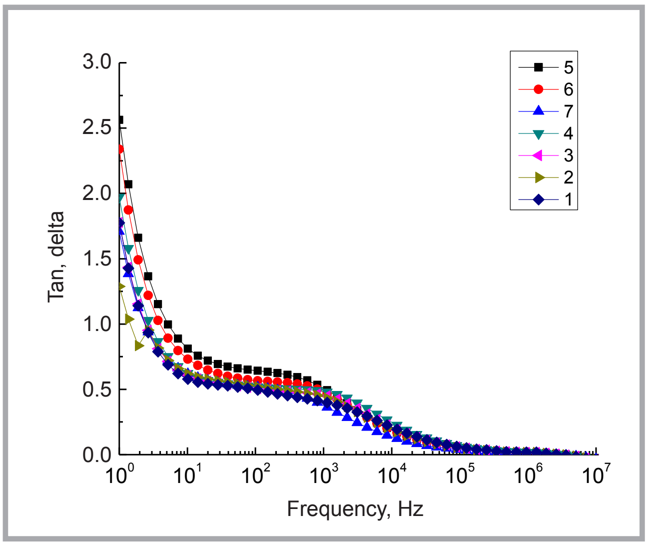

Figure 8. Influence of stitch length on the loss tangent.

75, 80, 70, 65, 55, 85, 60. The loss tangent is reduced to a minimum when the mark of the stitch length changes from 55, 85 to 60, and when the mark of the stitch length is reduced to 55, the loss tangent again increases; the loss tangent decreases again when the mark of the stitch length changes from 80, 70 to 65, and the loss tangent increases when the mark of the stitch length changes from 80 to 75. In the high frequency range, all seven loss tangent curves approximately coincide, with their values being close to 0; thus the impact of the stitch length on the loss tangent can be neglected.

When the fabric structure and the fineness of yarn are constant, then according to:

$$\delta = 1/d$$

the stitch length is sufficiently small that the fabric is not filled, thus the knitted fabric is more intensive. Because of this, if the knitted fabric is within a certain range, then the dielectric constant and loss tangent can be improved.

Conclusions

- When the yarn fineness was 59 tex and the mark of the stitch length – 75, the polyester knitted fabric exhibited the maximum real part and imaginary part of the dielectric constant.
- The real part of knitted fabric that was obtained with a yarn fineness of 59 tex was 4.06, the imaginary part – 1.67, and the loss tangent was 0.46 when the external electric field frequency was 1.13×10^3 Hz. At a low frequency band, the real part and imaginary part of knitted fabrics whose yarn finenesses were 59 tex, 32 tex and 45 tex are in descending order.
- At a low frequency ($f < 10^5$ Hz), the real part of the dielectric constant for polyester knitted fabrics whose mark of stitch lengths are 75, 70, 65, 60, 55, 80 & 85, are in descending order.

Acknowledgements

The authors would like to acknowledge the Project No. 2019TQ0181, 18JCTPJC62500, 18JC2DJC99900, 18JCYBJC86600, TJPU2 K20170105 and 2017KJ070.

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Received 09.10.2017 **Reviewed 11.07.2019**