The Biaxial Tensile Elastic Properties of Plain Knitted Fabrics

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Abstract: The biaxial tensile elastic properties of polyester and cotton plain knitted fabrics were investigated. Firstly, these fabrics were tested on a biaxial tensile instrument and subjected to biaxial extension at a fixed extension or a fixed load; the result shows that the coursewise and walewise stress and strain of fabric samples were affected by each other. Then the strip biaxial tensile (the fabric is stretched in one direction and the other direction is restricted) elastic properties of plain weft-knitted fabrics were measured at a fixed extension. An analytical model was used to predict the strip biaxial tensile property, and the theoretical predictions agree well with the experimental data.

Keywords: Plain knitted fabrics, biaxial extension, elastic properties, fixed extension.

1. Introduction

The biaxial tensile elastic properties of knitted fabrics play an important role both in processing and in end use of knitted materials. Moreover, the elastic properties of knitted fabrics influences the garment design and wearer comfort. Some papers presented the research on the uniaxial tensile elastic properties of knitted fabric [1-6], especially plain knitted fabrics, because of its basic structure.. This paper investigated the biaxial tensile elastic properties of polyester and cotton plain knitted fabrics.

Firstly, these fabrics were tested on a biaxial tensile instrument and subjected to the biaxial extension at a fixed extension and a fixed load; the result shows that the coursewise and walewise stress and strain of knitted fabrics were affected by each other. Then the strip biaxial tensile [7,8] (the fabric is stretched in one direction and the other direction is restricted) elastic properties of plain weft-knitted fabrics were measured at a fixed extension by a biaxial tensile tester, the result shows that this is a practical method.

2. Experimental

2.1 The biaxial tensile tester

To perform the test, a homemade biaxial tester was used [9]. The fabrics were subjected to equal biaxial extension ($\varepsilon_x=\varepsilon_y$) on a biaxial tensile instrument during testing, the tensile speed is at a constant rate (100mm/min) both in the wale and in the course direction, either during extension or return. Each sample size was set to 150 mm×150mm and the testing size was 100 mm×100mm.

2.2 Samples

Both polyester and cotton plain knitted fabrics were used to investigate their tensile elastic properties; the specifications are listed in Table 1. All samples were prepared and conditioned at 65% relative humidity and temperature of 20 ℃ for 24 hours before measuring. The preloading force was 1N to tighten the sample. Each testing was repeated for five times.

Table 1 Specifications of knitted fabric samples

No.	Yarn Specifications	Stitch Length l(mm)	Stitch density P_A (Wales /50mm)	Stitch density P_B (Courses /50mm)
1#	18tex Cotton	3.168	73	90
2#	11.1 dtex/36f PET	2.800	62	105

2.3 Testing

There are two different ways of tensile elastic tests: one is that the fabric is stretched to a fixed load of 10N for 30min, the jaw was returned to the initial pretension for 30min, the samples are cycled to the given load five times; the other one is that the fabric is held at a fixed extension of 15% for 30min, the jaw was returned to the initial length for 30min, the samples are cycled to the given load five times. The sample is clamped and is stretched along the walewise

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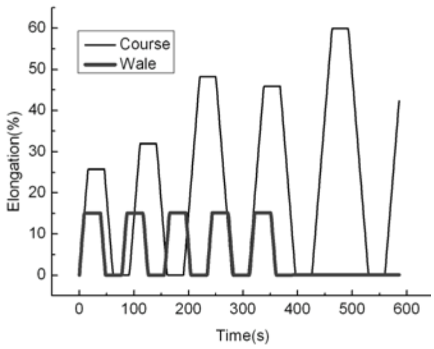
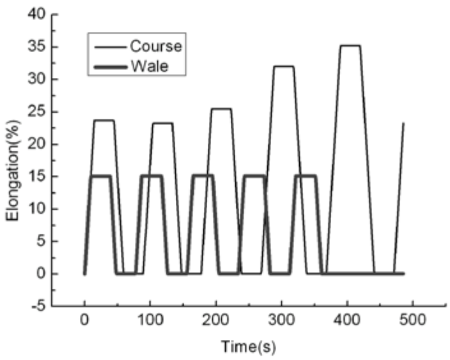
and coursewise direction up to a maximum load or a maximum extension.

The relationship between the elongation and time is illustrated in Figure 1. It shows typical curves at a fixed extension of 15% for plain knitted fabrics 1# and 2#. The thick line is in walewise direction and the thin line is in coursewise direction. The curve indicates that in five cycles ,specially the last three cycles, does not really show the biaxial extension of plain knitted fabrics, because the extension in the coursewise direction of fabrics is very easy than in the walewise direction ,which means that the deformation and recovery are different in two directions, the sync extension can not be obtained.



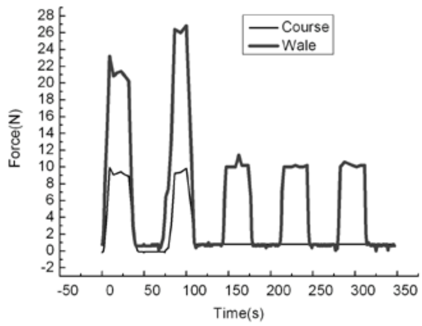
(1) Sample 1#



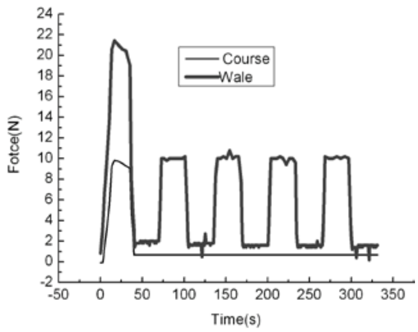
(2) Sample 2#

Figure 1 Relationship between elongation and time.

Figure 2 shows the elongation-time curves for plain knitted fabrics 1# and 2# with the machine set at a fixed load of 10N, the thick line is in walewise direction and the thin line is in coursewise direction. It indicates that there is no possibility of reaching the same load in two directions at equal biaxial extension ($\varepsilon_x=\varepsilon_y$). If the x-direction force is 10N, the y-direction force will be bigger than 10N, but if only considering y-direction extension, the force in y-direction will arrive at 10N.This is because the tensile properties in these two directions are very different, the stress of the coursewise direction is different from the walewise direction at the same strain.



(1)Sample 1 #



(2) Sample 2#

Figure 2 Relationship between force and time.

So the strip biaxial tensile property (the fabric is stretched in one direction and the other direction is restricted) was used in this study and the machine was set at a fixed extension of 15%.

3. Theory

According to TAIBI's theory [10], the linearity of the tensile deformation of fabrics is always lower or equal to 1, linearity functions for tensile and recovery can be respectively approximated as follows:

$$IT\ (\varepsilon) = B\varepsilon + 1 \quad \text{.with B is a constant<1} \quad (1)$$

$$IT\ '(\varepsilon) = B'\varepsilon + 1 \quad \text{.with } B' \text{ is a constant<1} \quad (2)$$

Where, LT=tensile linearity in extension, LT'=tensile linearity in recovery, ε (in %) is the extension.

From the tensile and recovery curve, we can obtain four parameters, ε_0 (in %) the fixed extension, $f(\varepsilon_0)$ (in N/cm) the relative stress corresponding to the fixed extension, and WT=work of fixed extension ε_0 during the tensile process.

$$WT = \int_0^{\varepsilon_0} f(\varepsilon)d\varepsilon \tag{3}$$

LT is the ratio of *WT* and *WOT*.

$$LT = \frac{WT}{WOT} \tag{4}$$

WOT is the area of the triangle $O\varepsilon_0 f(\varepsilon_0)$.

$$WOT = \frac{f(\varepsilon_0)\times\varepsilon_0}{2} \tag{5}$$

WT' =work of fixed extension ε_0 during the recovery process.

$$WT' = -\int_{\varepsilon_0}^{0} f'(\varepsilon)d\varepsilon \tag{6}$$

RT (in %) is the resilience, the ratio of WT' and *WT*.

$$RT = \frac{WT'}{WT}\times 100 \tag{7}$$

Because $f(\varepsilon)$ is a monotonous function on [0, ε_0], form Eq.1, Eq.2, and Eq.3, we have

$$2\int_0^{\varepsilon} f(x)dx = \varepsilon f(\varepsilon)(B\varepsilon+1) \tag{8}$$

According to hypothesis, the derivation of Eq.8 with respect to ε is given as

$$2f(\varepsilon) = f(\varepsilon)(B\varepsilon+1) + \varepsilon(B\varepsilon+1)\cdot\frac{\partial f(\varepsilon)}{\partial\varepsilon} + \varepsilon f(\varepsilon)B$$

$$\frac{(\frac{\partial f(\varepsilon)}{\partial\varepsilon})}{f(\varepsilon)} = \frac{1-2B\varepsilon}{\varepsilon(\varepsilon B+1)} = \frac{1}{\varepsilon} - 3\frac{B}{(B\varepsilon+1)}, \varepsilon\neq 0 \tag{9}$$

Because $f(\varepsilon)$ is a positive function, integrating Eq.9 between ε and ε_0, we obtain

$$\ln f(\varepsilon) = \ln\frac{\varepsilon}{(B\varepsilon+1)^3} + \ln[f(\varepsilon_0)\frac{(B\varepsilon_0+1)^3}{\varepsilon_0}]$$

Then

$$f(\varepsilon) = \frac{\varepsilon}{(B\varepsilon+1)^3}[f(\varepsilon_0)\frac{(B\varepsilon_0+1)^3}{\varepsilon_0}], \varepsilon\in[0,\varepsilon_0] \tag{10}$$

From Eq.1 and Eq.4, Eq.5, we obtain the relation between stress and strain. It is given by the following equation:

$$f(\varepsilon) = \frac{2\cdot LT^2\cdot WT\cdot\varepsilon}{\varepsilon_0^2(\frac{LT-1}{\varepsilon_0}\varepsilon+1)^3} = \frac{2LT^2\cdot WT\cdot\varepsilon\cdot\varepsilon_0}{[(LT-1)\varepsilon+\varepsilon_0]^3}, \varepsilon\in(0,\varepsilon_0) \tag{11}$$

The recovery process is similar to the tensile process, we have

$$f'(\varepsilon) = \frac{2\cdot LT'^2\cdot WT'\cdot\varepsilon}{\varepsilon_0^2(\frac{LT'-1}{\varepsilon_0}\varepsilon+1)^3}, \varepsilon\in(\varepsilon_1,\varepsilon_0)$$

According Eq.4 and Eq.7, we obtain

$$\frac{LT}{LT'} = \frac{WT}{WT'} \tag{12}$$

$$LT' = \frac{WT'}{WT}\cdot LT = \frac{LT\cdot RT}{100} \tag{13}$$

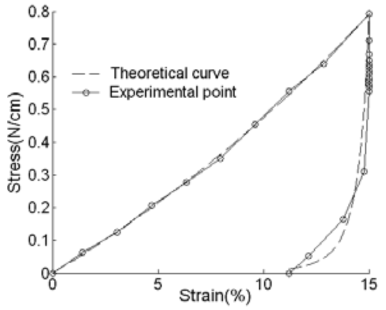
From Eq.12 and Eq.13, the relation between stress and strain during recovery process, is as follows:

$$f'(\varepsilon) = \frac{2\cdot WT\cdot LT^2\cdot RT^3\cdot\varepsilon\cdot\varepsilon_0}{[(LT\cdot RT-100)\varepsilon+100\varepsilon_0]^3}, \varepsilon\in(\varepsilon_1,\varepsilon_0) \tag{14}$$

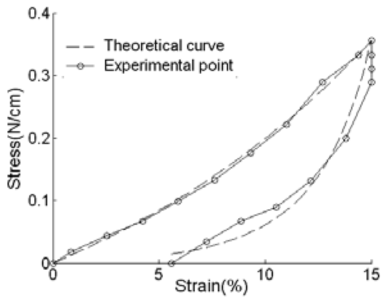
4. Results and discussion

The experimental results of the strip biaxial tensile property of polyester and cotton plain knitted fabrics at a fixed extension are plotted in Figures 3 and 4. The parameters (*WT, LT,* ε_0*, RT*) can be obtained from the curves resulting from the tests of the two samples. Then the theoretical tensile curves of polyester and cotton plain knitted fabrics can be gained by introducing these parameters into Eq.11 and Eq.14.

Figures 3 and 4 present the comparison between the theoretical predication and the experimental data. Good agreements with experimental results were achieved during the tensile process; but there is a slight difference between these curves on the portion of the recovery process. This difference is partly due to errors of parameter precision and due to an error in assumption of the linearity $LT(\varepsilon)$, and the other important reason is caused by the pause for 30min at a fixed extension, and there is some tension decay and residual extension which prohibits fabrics to return to the initial state.

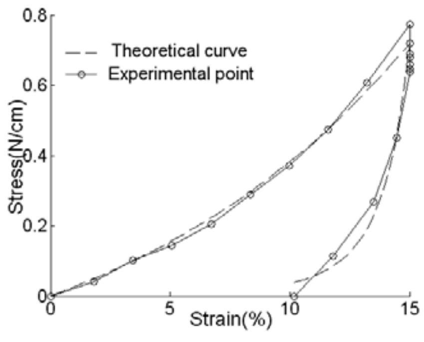


(1)Coursewise

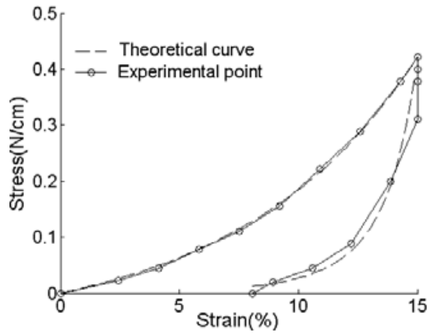


(2)Walewise

Figure 3 Experimental and theoretical tensile diagrams of sample 1#.



(1) Coursewise



(2)Walewise

Figure 4 Experimental and theoretical tensile diagrams of sample 2#.

5. Conclusions

The mutual influence of coursewise and walewise stress and strain of knitted fabrics was observed when the samples were tested on a biaxial tensile instrument and subjected to biaxial extension at a fixed extension or a fixed load. An analytical model was used to predict the strip biaxial tensile curve. The results show that the theoretical predictions agree well with the experimental data. The strip biaxial tensile test is a practicable method for investigating the biaxial tensile elastic properties of knitted fabrics.

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