Computational Modeling of Fabric Surface Structure

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Summary

This paper reports the results of an investigation on the effects of the yarn bending rigidity on the fabric surface structure. The bending rigidity is regarded as the multiple of the elastic modulus E, and the moment of inertia of the cross-section of the yarn (EI). The study was based on an analytical model adopted from the elastic theory. The experimental results are found to be in reasonable agreement with the theoretical values.

Introduction

In the earlier work an analytical model was developed for the deflection of weft (warp) in a plain-weave fabric[1]. The model was based on a two fixed ends elastic beam deflected at the middle by a vertical load [2]. The effect of two factors i.e. normal load and thread spacing on the yarn protrusion from the fabric surface were studied. It was shown that the two factors were in a good agreement with the yarn protrusion from the fabric surface. The model also revealed that the mechanical properties of the yarn are also important factors affecting the deflection of the weft (warp). It is therefore of interest to investigate the effect of yarn rigidity i.e. elastic modulus of the yarn E, and moment of inertia of the cross section of the yarn I, on the fabric surface structure.

Deflection Estimation

According to the theoretical model adopted for the deflection of weft in a plain weave fabric, the maximum deflection was found to be:

$$y = \frac{PL^3}{192E.I} \tag{1}$$

Where
y = maximum deflection at the middle of the weft.
P = vertical load.
L = the distance between supports (the distance between two adjacent warp).

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E = the elastic modulus of the weft.
I = the moment of inertia of cross-section of the weft.

Consider an individual practical case in which P, L are constant and the variables are E and I. Appling logarithm to the both sides of the Equation (1) gives:

$$\log y = \log \frac{PL^3}{192} - \log E.I \tag{2}$$

Or

$$\log y = K - \log E.I \tag{3}$$

In this case, the protruding yarn density is related to the two variables of E and I or yarn bending rigidity (E.I).

Estimation of protruding yarn density

In order to investigate the effect of yarn bending rigidity on the yarn protrudes from fabric surface, we prepared samples of plain-weave fabrics with different types of weft yarns produced in five different spinning systems i.e. combed, carded, air-jet, open-end and core-spun. All other parameters of the weft, warp and the fabric were identical. The only independent variable was the system of the production of the weft yarns which lead to variable bending rigidity of the weft yarns (EI). The weft yarns, for all samples, were cotton with a linear density of 28/1 Tex. The warp yarns were cotton-polyester with a linear density of 7/2 Tex. The warp and weft thread densities were 27 ths/cm and 18 ths/cm respectively.

Protruding yarn density is depicted by the intensity of protruding yarn clustered along a given direction and is proportional to the magnitude of the prominent angular power spectrum (A.P.S) peaks. A.P.S is obtained by the gathering the values of the two-dimensional power spectrum p(u,v) taken over sectors centered at the origin [5-7].

Measurement of yarn bending rigidity

The yarn bending rigidity is calculated as: E.I, where E, is the elastic modulus of the weft and I, is the moment of inertia of the cross-section of the weft.

Measurement of the moment of inertia of the cross-section of the weft yarns

Longitudinal images of prepared yarns are captured by means of a CCD camera mounted on a compound microscope. The images are digitized in a PC compatible computer. Image data are stored in 8 bits per pixel, which allows for 256 gray intensity levels. The diameters of yarns were then calculated using software. In each case 50 different samples were tested. Finally, the moment of inertia of the cross-section of the yarns were calculated as follows:

$$I = \frac{\pi r^4}{4} \tag{4}$$

Measurement of the weft yarns modulus

The elastic moduli of the weft yarns were also needed. These were obtained from the stress- strain curves of the samples. The tensile tests were carried out on a tensile tester at an elongation rate of 80 mm/min, with a gauge length of 500 mm. Five different weft yarns were examined and in each case 30 different samples were tested. All the samples were conditioned in a standard room 20°C and 65% R.H. for 48 hours before the experiments. The moduli of yarns were then obtained according to the slop of stress-strain curves at the origin.

Results and Discussion

Fig. 1, 2 give typical photograph of two dimensional power spectrum, and angular power spectrum (A.P.S), respectively, for open-end sample. Weft protruding yarn densities were calculated using the A.P.S method, and are provided in table I. The magnitude of the dominant peaks on the A.P.S at angles of 90 and 180 are warp and weft protruding yarn densities, respectively [1,4]. In order to investigate the relationship between the protruding yarn density (y) and the yarn bending rigidity, the values of E, and I, are needed. These are provided in table I.

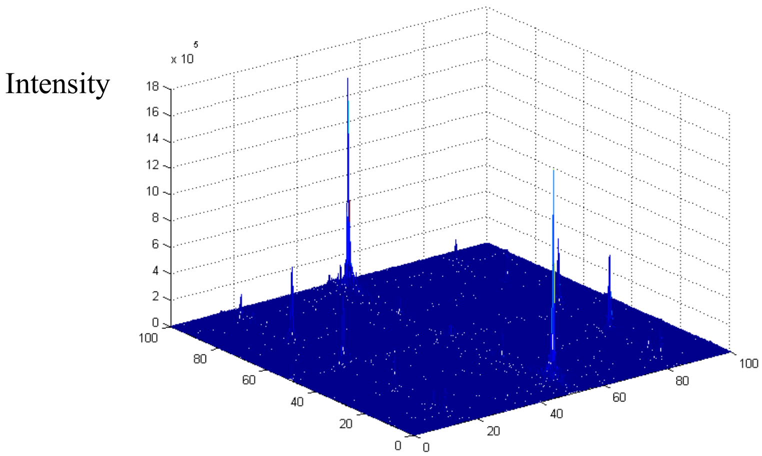

Fig. 1 Typical two dimensional power spectrum of the open-end sample.

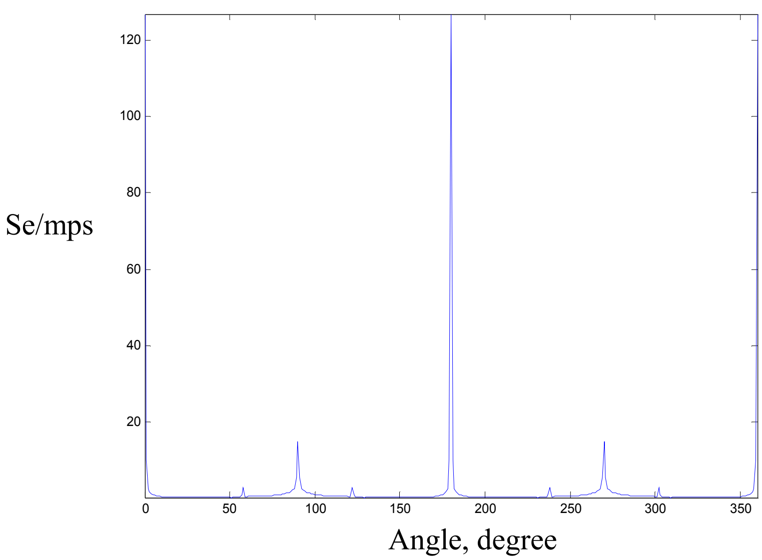

Fig. 2 Typical normalized angular power spectrum of the open-end sample.

Table I. Some properties of samples and weft yarns used in this study

Sample	Weft protruding density(y) Se/mps*	Diameter (d) (mm)	The moment of inertia(I) $(mm^4)\times10^{-4}$	Modulus (E) (gf/mm^2)	Bending rigidity(EI) $(gf\text{-}mm^2)$
Combed	5.8	0.202	0.817	25829	2.110
Carded	13	0.158	0.306	35624	1.090
Open-end	130	0.204	0.850	16787	1.427
Air-jet	112	0.152	0.262	28106	0.736
Core-spun	60	0.146	0.223	32688	0.729

*Se/mps: spectral energy/mean of power spectrum

Fig. 3 shows the plots of variation of the log weft protruding yarn density (y) versus log EI. As can be seen, the data points are in an acceptable inverse linear correlation, with a coefficient of regression of R= -0.61. The constant value is found to be a=1.65 and the gradient of the line is -1.8. The value of the gradient of the line obtained from the practical experiment (b= -1.8 in Fig. 4) is in close agreement with the theoretical value of -1 (from Equation (3)).

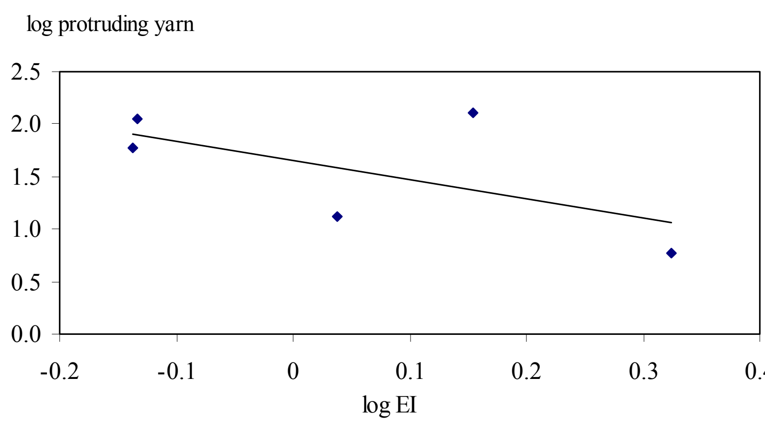

Fig. 3 Variation of log protruding yarn VS log EI, R= -0.61, b= -1.8, a=1.65

There are some explanations for the discrepancy of the experimental values from the theoretical values. First, it was assumed, in the theoretical model, that the cross-section of the yarn is circular, whereas in the practical cases the cross-section of the weft yarns deviates from the circular form which can lead to the deviations of the practical values from the theoretical values. Another possible explanation for the discrepancy may be due to the normal load (vertical load P in Equation (2)). It was also assumed that the normal load is constant for all samples. However the weft yarns have been produced in different systems and, consequently, the surface friction of the weft yarns may be different. This may lead to some variations of normal load and cause some discrepancy between the experimental values and the theoretical values.

Conclusion

The theoretical model proposes that the rigidity of the weft yarn is an important parameter inversely affects the protruding yarn density from the fabric surface. However the results of this study confirm the theoretical model and indicate that the rigidity of the yarn inversely affects the fabric surface protrusion. There is an inverse correlation between the rigidity of the weft yarn (EI) and the yarn protruding density with a correlation coefficient of R= -0.61.

Acknowledgments

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Reference

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