CHARACTERIZATION OF STAPLE YARNS BY ACOUSTIC DYNAMIC MODULUS

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Abstract

The acoustic or sonic pulse-propagation technique for the measurement of dynamic elastic modulus has the advantage of not being dependent on the sample cross-sectional characteristics. This technique also gives a direct measure of modulus rather than the indirect measure in the form of load versus extension. The sonic tests are relatively simple to apply and are nondestructive. The values of sonic modulus of fibrous structures are dependent on the orientation of components and packing density as well. The main aim of this work is to quantify effect of yarn twist on the sonic modulus of staple yarns from polypropylene fibers. The results are compared with selected models of yarn twist influence on the mechanical properties of staple yarns. The correlation between yarn orientation factor defined by Pan and sonic modulus are shown. The sonic modulus is compared with tensile modulus of yarns.

Introduction

Studies of the fundamental dynamic mechanical properties of textile products are of prime importance if improvements to textile-processing equipment are to characterize textile structures. The acoustic or sonic pulse-propagation technique for the measurement of dynamic elastic modulus has the advantage of not being dependent on the sample cross-sectional characteristics. This technique also gives a direct measure of modulus rather than the indirect measure in the form of load versus extension. The sonic tests are relatively simple to apply and are nondestructive. The values of sonic modulus of fibrous structures are dependent on the orientation of components and packing density as well.

The acoustic dynamic modulus of yarn is much lower than acoustic dynamic modulus of fibers (corresponding multiplicative factor is in the wide range from 0.05 to 0.6). The decrease in acoustic dynamic modulus of yarns is influenced by the twist level mainly. From the acoustic dynamic modulus of yarns E_y at some twist level Z it is possible to calculate the approximate orientation factor. Increase of the polypropylene yarn twist level leads to the decrease of the yarn acoustic and initial tensile modulus and orientation of fibers as well.

The geometrical models based on the ideas of Gegauff (1907), Pan (1993, 1996) and White (1975) are here compared with predicted mean orientation from measurements of yarns acoustic modulus and yarn initial tensile modulus

Theoretical Part

Let the staple yarn is composed of thin, elastic cylindrical rods with dynamic modulus E and density ρ. Let the longitudinal sonic waves propagation is investigated. The rate of these waves spread c is computed from well-known relation (Graff, 1975).

$$c = \sqrt{(E/\rho)} \qquad (1)$$

The acoustic dynamic modulus of yarns is much lower than acoustic dynamic modulus of fibers (multiple factor is in the wide range from 0.05 to 0.6). Acoustic dynamic modulus of yarns decrease is influenced by the twist level mainly. In 1907 Gegauff (1907) proposed a simple analysis to correlate the twist angle of yarn β_D with the yarn modulus E_y. Based on yarn helical model the tangents of surface fiber helix angle β_D is directly connected with number of twists Z and yarn diameter D i.e.

$$tg\beta_D = \pi D Z \qquad (2)$$

Yarn acoustic modulus E_y at the twist level Z is then function of fiber modulus E_f

$$E_y = E_f \cos^2 \beta = E_f /(1 + (\pi D Z)^2) \tag{3}$$

For definition of real yarn diameter it is possible to define yarn packing density μ. Packing density is generally defined as ratio between fiber volume V_f and whole yarn volume V_y, as it is shown below

$$\mu = V_f / V_y = 4T / \pi D^2 \rho \tag{4}$$

where T is yarn fineness, D is yarn diameter and ρ is fiber density. Packing density μ can be calculate by using the following relationship (Neckář, 1990).

$$\frac{\left(\frac{\mu}{\mu_m}\right)^{5/2}}{\left[1-\left(\frac{\mu}{\mu_m}\right)^3\right]^3} = \frac{M\sqrt{\pi}}{2\mu_m^{5/2}\sqrt{\rho}}\left(Z\, T^{1/4}\right)^2 \tag{5}$$

where M is the material and technology parameter and μ_m is the limit packing density. A suitable value of parameter M for polypropylene yarns was found in (Křemenáková and Militký, 2007).

White et al. (1975) proposed more complex analysis based on the continuum mechanics. Their final equation has the form

$$E_y = E_f \left(\frac{1}{4} + \frac{9F}{4} + \frac{3F}{(1-F)} \ln \sqrt{F}\right. \tag{6}$$

where $F = \cos^2 \beta_D$. Pan (1993, 1996) derived orientation factor η_β as a function of surface fiber helix angle β_D and yarn Poisson ratio η

$$\eta_\beta = \frac{2\beta_D(1-\eta) + (1+\eta)\sin 2\beta_D}{4\beta_D} \tag{7}$$

Poisson ratio η has the form (Pan, 1993)

$$\eta = \frac{\sin^5 \beta_D}{2\left(1-\cos^3 \beta_D\right)\left(\frac{1}{2}\beta_D - \frac{1}{4}\sin 2\beta_D\right)} \tag{8}$$

From the acoustic dynamic modulus of yarns E_y at some twist level Z it is possible to calculate the approximate orientation factor η_β from simple relation

$$\eta_\beta = \frac{E_y}{E_b} \tag{9}$$

where E_b is the acoustic dynamic modulus of yarns without twist (i.e. fibrous bundle). The E_b is in fact replacing the fiber modulus in eq. (3) and (6). The eq. (9) can be used for prediction of orientation from yarn initial tensile modulus as well.

Experimental Part

The thirteen compact polypropylene yarns of the same fineness T = 25 tex with different twist were spun. Instead of twist level Z the Phrix's twist coefficient α [$\mathrm{m}^{-1}\mathrm{ktex}^{2/3}$] was computed

$$\alpha = Z\ T^{2/3} \tag{10}$$

Properties of polypropylene fibers are summarized in the Table 1. Yarns were produced in the pilot plant conditions so as to achieve the smallest and greatest possible twist, twist factor was from 30 to 98 [$\mathrm{m}^{-1}\ \mathrm{ktex}^{2/3}$]. The yarns sonic velocity was measured on the apparatus Dynamic Modulus Tester (Lawson Hemphill) with piezoelectric crystal transducer (see fig. 1).

Figure 1 Lawson Dynamic modulus Tester PPM-5R

The initial tensile modulus of yarns was calculated from smoothed stress strain curves measured on the tensile testing machine under standard conditions. The smoothing was realized by using of optimal cubic smoothing splines (Meloun, 2004). The limit packing density μ_m = 0.7 and optimal value of parameter M = 0.0919 [m] for polypropylene yarns were used.

Table 1. Selected polypropylene fiber properties

fiber properties	mean value	95% conf. interval
Fineness [tex]	0.225	0.213 - 0.236
Length [mm]	48.84	48.19 – 49.49
Strength [N/tex]	0.308	0.301 - 0.315
Deformation at break [%]	55.15	48.78 - 61.53

Results and Discussion

The acoustic dynamic modulus of yarns without twist E_b was calculated from linear dependence of yarn sonic velocity on the twist coefficient α (extrapolation to the α = 0). This dependence is shown in fig. 2.

The linear dependence of sonic velocity on the twist coefficient is fairly good with squared correlation coefficient R^2 = 0.77. The extrapolated sonic velocity of yarns without twist is 1.898 km/s. Corresponding acoustic dynamic modulus of yarns without twist E_b calculated from eq. (1) is equal to 3.367 GPa.

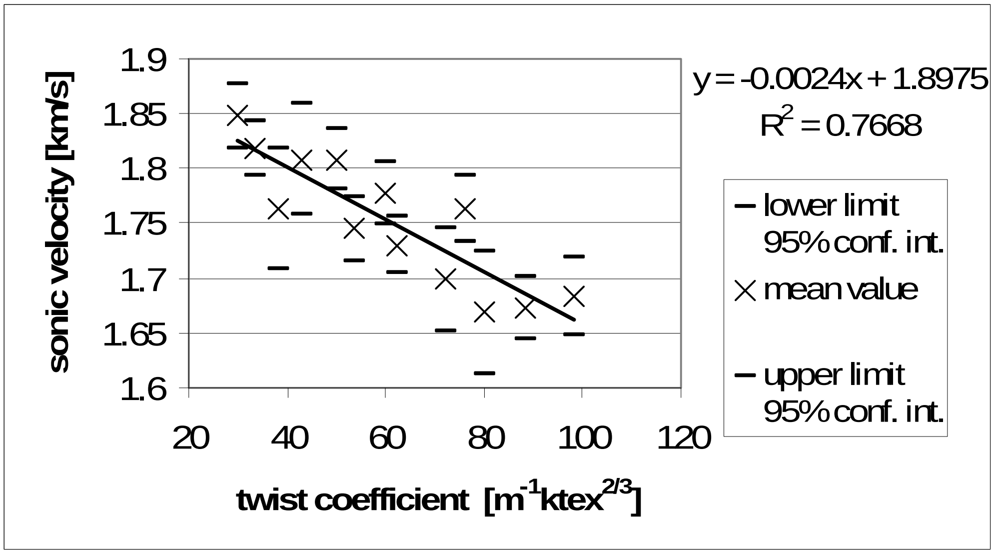

Figure 2 Sonic velocity as function of yarn twist coefficient

The dependence of yarn initial tensile modulus on the twist coefficient α is shown in fig. 3. The linearity of this dependence is very good with squared correlation coefficient $R^2 = 0.918$

Extrapolated initial tensile modulus of yarns without twist is equal to 1.624 GPa. It is clear that the static modulus is lower in comparison with sonic (dynamic) modulus.

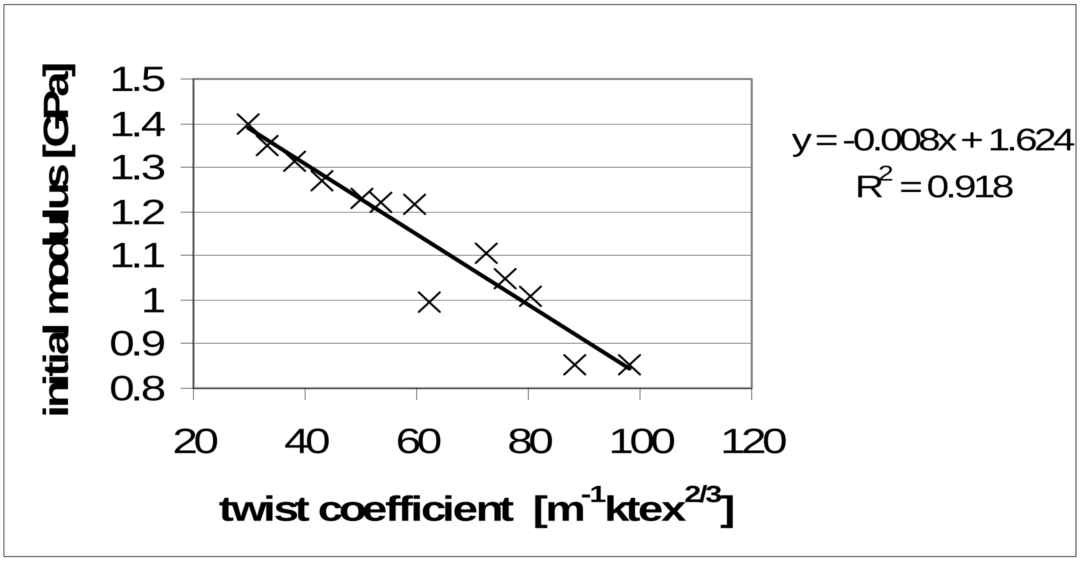

Figure 3 Initial tensile modulus as function of yarn twist coefficient

The experimental orientation factors computed from sonic modulus and initial tensile modulus are shown in the fig. 4. The lines corresponding to the orientation factor calculated from Gegauff, Pan and White models are shown as well.

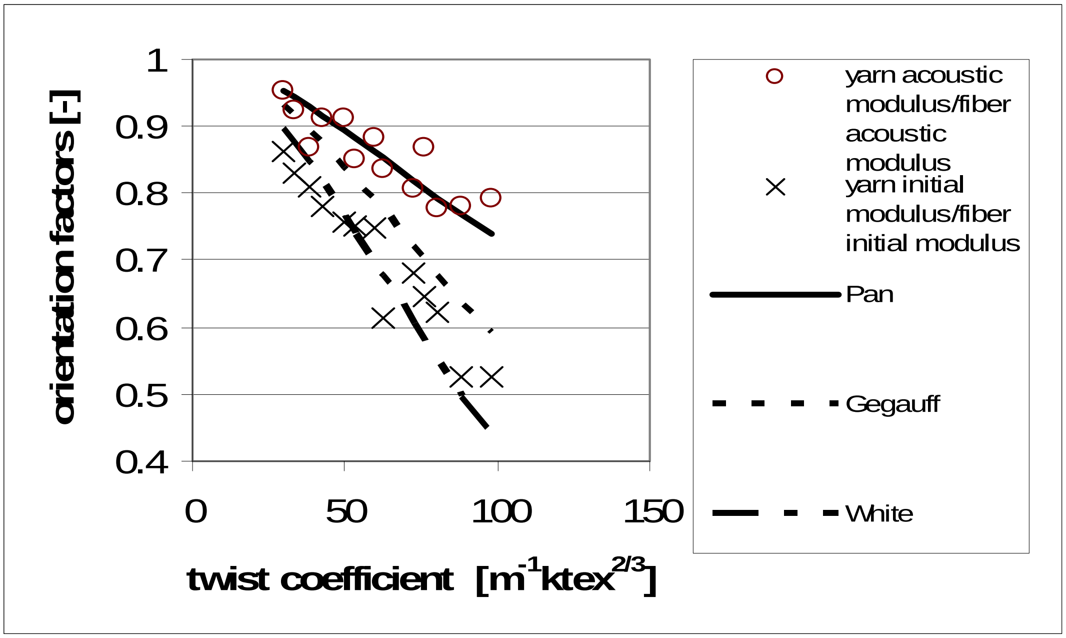

Figure 4 Various orientation factors as function of yarn twist coefficient

Conclusion

The influence of twist factor on the orientation of polypropylene staple yarn was studied. With the increasing of twist coefficient yarn acoustic modulus and yarn initial modulus is decreasing. The linear dependence of POP yarn acoustic modulus and POP yarn initial modulus on the twist coefficient were found. The acoustic dynamic modulus and initial modulus of yarns without twist were calculated from these linear dependences.

Experimental orientation factors at various twist level were calculated as ratio between acoustic (initial) yarn modulus at some level and acoustic (initial) modulus of yarn without twist. It was found that for prediction of orientation factor from sonic modulus is the best the Pan model (see eq. (7)) and for prediction of orientation factor from initial tensile modulus is the best the White model (see eq. (6). The Pan model is suitable for prediction of yarn strength.

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