MODELING OF POLYPROPYLENE YARN PROPERTIES

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Introduction

In this work, the possibilities of prediction of polypropylene yarn packing density and strength are described. These models are based on the characteristics of fibers (i.e. fineness, mass density, bundle strength), and also on the yarn fineness and twist. Models used for prediction of cotton yarn properties do not take into account changes in the properties of yarn, which occurs during a tensile deformation (see [1], [2]). Generally, yarns from synthetic fibers are closer and more regularly arranged. Synthetic fibers are longer, with lower bending rigidity and have much higher break elongation than cotton fibers. For these reasons, the cross-section of fiber is significantly changed during stressing and therefore for prediction of yarn strength the fiber elongation factor was used. While studying the effect of the twist on the strength of polypropylene yarn the different mechanism in comparison with cotton yarn strength was found. With increasing twist of the polypropylene yarn the yarn strength is decreasing.

Theoretical part

Relative yarn strength σ_y is frequently expressed as product of relative fiber strength σ_f and correction factor ϕ_{fy} expressing utilization of fibers strength in yarn.

$$\sigma_y = \sigma_f \phi_{fy} = \sigma_b \phi_{by} = \sigma_f \phi_{fb} \phi_{by} \qquad (1)$$

Utilization of fiber strength in yarn is product of fiber strength utilization in bundle ϕ_{fb} and utilization of bundle strength in yarn $\phi_{by.}$ The σ_b denotes bundle strength. The fiber strength distribution of Weibull two-parameter type was proposed by Pan [3], [4]. Simple approximate relation for utilization of fiber strength in bundle based on Pan result was derived in [1]

$$\phi_{fb} = u^u \exp(-u) / \Gamma(1+u), \quad u = 0,909 v_{\overline{\sigma_f}} \qquad (2)$$

where the symbol Γ() is gamma function and $v_{\overline{\sigma_f}}$ is variation coefficient of fiber strength.

Utilization of bundle strength in yarn was derived by Pan [3], [4]

$$\phi_{by} = V_f n_\beta \qquad (3)$$

Volume ratio (packing density) V_f and orientation factor n_β as correction factors are here used. Orientation factor η_β is function of helix angle β_D and yarn Poisson ratio η [3].

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

Packing density is generally defined as ratio between fiber volume V and whole yarn volume V_y, as it is shown below

$$\mu = V_f / V_y = 4T / \pi D^2 \rho \qquad (5)$$

where T is yarn fineness, D is yarn diameter and ρ is mass density. Packing density μ can be calculate by using the following relationship [5]

$$\frac{\left(\frac{\mu}{\mu_m}\right)^{5/2}}{\left[1-\left(\frac{\mu}{\mu_m}\right)^3\right]^3} = \frac{M\alpha^2}{D_s \rho \mu_m^{5/2}} = \frac{M\sqrt{\pi}}{2\mu_m^{5/2}\sqrt{\rho}}\left(ZT^{1/4}\right)^2 \qquad (6)$$

where M is the material and technology parameter and μ_m is the limit packing density. A suitable value of parameter M for compact, ring, rotor and new type of cotton yarns was found in [5] and [1].

Based on the careful inspection of above mentioned models the modified relation for prediction of polypropylene yarn relative strength was proposed

$$\sigma_P = \sigma_f(1+\varepsilon_f)\phi_{fb}\phi_{by}^* = \sigma_f(1+\varepsilon_f)\phi_{fb}\mu\eta_\beta^* \qquad (7)$$

where ε_f is fiber deformation at break and η_β^* is corrected orientation factor derived by Pan (4). The so called true stress [7] involving a change in yarn geometry was incorporated to the prediction of relative yarn strength.

Experimental part

For monitoring of the influence of the twist factor on the yarn strength two groups of thirteen compact polypropylene yarns of the same fineness 25 tex with different twist were spun. Two types of polypropylene fibers for yarns production were used. Fiber fineness, length and deformation at break were the same, but strength of fiber type 1 was statistical significantly higher then strength of fiber type 2. Yarns have been produced in the pilot plant conditions so as to achieve the smallest and greatest possible twist, twist factor was from 34 to 105 [m^{-1} $ktex^{2/3}$]. The yarn packing density, diameter, strength and deformation at break were measured.

Yarn packing density was evaluated from yarn cross-sections by using of image analysis. 30 cross-sections were prepared from each sample of yarns. The Secant method based on reconstruction of fiber sections around their centers was used [5], [6]. Result from this method is the radial course of packing density trace. We assume that the border between yarn core and a surface layers is approximately on the radial packing density 0.15. The curve of the radial packing density was evaluated and yarn diameter *D*, which correspond to the packing density μ = 0.15 was computed. Radial packing density trace was replaced by constant value calculated from a yarn cross-section as ratio between sum of fiber areas of circle having diameter *D* and areas of this circle.

With the increasing of yarn twist coefficient the packing density is slowly increasing till limit value. According to the relationship (6) and the limit packing density μ_m = 0.7 optimal value of parameter *M* = 0.0919[m] for yarns of group 1 were found. The same parameters can be used for prediction of yarn packing density of group 2.

The measured yarn relative strength together with 95% confidence intervals is given in the fig. 1. For prediction of the strength the relationship (6) has been used. In fig. 1 is shown, that the predicted values of the relative strength of the yarn are mostly in the confidence intervals of measured values or its limits. The packing density and yarn diameter are the same for both yarn groups. Strength of yarns of group 1 is higher then strength of yarns of group 2 due to higher fiber strength only.

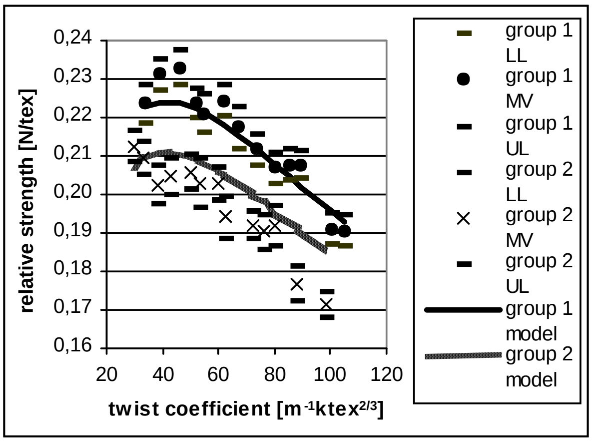

Fig. 1 Influence of twist coefficient on the polypropylene yarn relative strength (95% confidence intervals, LL-lower limit, MV-mean value, UL-upper limit)

Conclusion

In this work the influence of twist factor on the strength of yarn made of polypropylene fibers has been studied. It was shown that the strength of the yarn is influenced mainly by the fiber bundle strength, which depends on the single fiber strength and its coefficient of variation. Another factor is friction between the fibers, which are replaced by the yarn packing density. With the increasing of twist the packing density is increased to the limit value approximately 0.7 to 0.8. An important factor is the orientation of fibers in the yarn. With the increasing twist is the orientation factor decreasing and yarn strength is reduced. Known is the reduction of strength due to twist for multifils [5] and ropes [8]. Packing density factor and orientation factor are multiplied. In the case of cotton the yarn packing density firstly increases significantly up to critical twist and it affects more strength than a factor of orientation [5]. Polypropylene yarns are characterized by higher levels of arrangement of fibers, and therefore with the increase of twist factor the packing density is increasing slowly. The significant factor is the orientation, which leads to the reduction of yarn strength. Another important factor is the decreasing of the cross-section area due to the tensile deformation.

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