Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 7 (16): 2376-2379, 2007
ISSN 1812-5654

Viscoelastic Behavior of Starch Sized Warps

Samah Maatoug, Néji Ladhari and Faouzi Sakli
Textile Research Unit, Ksar Hellal, High Technology Institute,
Ksar Hellal, Hadj Ali Soua, 5070 Ksar Hellal, Tunisia

Abstract: In many applications, the most important properties of spun yarns are their tensile characteristics. Therefore, the control of manufacturing processes inevitably requires knowledge of the mechanical behavior of textile materials in order to evaluate yarn strength during the various stages of manufacturing. We have analyzed the application of one of the most suitable model to characterize the viscoelastic properties of sizing yarns. Some modifications of the Standard Linear Solid (SLS) and Zurek models improve their ability to model viscoelastic behavior. Therefore, viscoelastic modeling based on mechanistic models for fitting experimental data of tensile tests was investigated. The rheological model of the sized yarn can be justified by considering the two models: the unsized yarn and the sizing film.

Key words: Stress-strain, viscoelastic, Maxwell element, non-linear spring, sizing yarns

INTRODUCTION

The tensile properties of yarns play a phenomenal role in the processability and in the quality of the final products. However, the values of sizing yarn tenacity and breaking strain represent only about the terminal point of stress-strain curve. In many situations, as weaving, winding and spinning, knowledge of the full course of the stress-strain curves is more desirable, which is, partially, a function of the nature and structural arrangement of the constituent fibers in the yarns (Ghosh *et al*., 2005; Vangheluwe, 1993).

The mechanical properties of solids can be explained by hook's law for infinitesimal strains. Similarly, the properties of viscous liquids can be explained by Newton's law infinitesimal rates of strain. However, for finite strains or finite rates of strain, these laws are unable to explain the mechanical behavior of either elastic solids or viscous liquids. Some materials exhibit behaviors which are a combination of elastic solid-like and a viscous liquid-like behavior, even when strain and rate of strain are infinitesimal. Such a material does not maintain constant deformation under constant stress; instead, it 'creeps'. Also, if it is constrained at a constant deformation, the stress required to keep it in the deformed state relaxes (Nachane *et al*., 1995a,b). Such materials are called viscoelastic materials (Vangheluwe, 1992a). In a shear strain is imposed on a specimen within a brief period of time and it is then constrained to remain at that strain, the stress developed in it remains constant for an elastic solid and drops to zero at the moment when strain is stopped in a viscous liquid (Ghosh *et al*., 2005). But in the case of a viscoelastic material, the stress decays with time. The rheological equation describes the relationship between stress-strain and relaxation curves. Linear viscoelastic behaviour occurs within small deformations when the microstructure is not modified (Persoz, 1960). This is explained by linear viscoelastic models. Mechanical behaviour in large deformations can only be explained by non-linear viscoelasticity.

Polymers or fibers are viscoelastic and their mechanical behavior can be adjusted using mechanistic models consisting of elements such us Hook springs, Newton dashpots, unidirectional friction elements and inertional elements, which, when correctly combined could produce the mechanical behavior of the material under mechanical stress. The Vangheluwe and the zurek models were used to describe the mechanical behavior of cotton yarns (Manich *et al*., 1990; Vangheluwe, 1992b; Ussman *et al*., 1999).

MATERIALS AND METHODS

Sized and unsized cotton warps (12,5 Nm, 14 trs cm^{-1} twist level) were used. Yarns were produced in a ring spinning manufacturing machine. All yarns were sized with a combination of native maize starch, urea and lubricant (fatty acids and emulsifier). Table 1 summarizes the test conditions.

Before mechanical testing, the samples were conditioned for 24 h in standard atmosphere. Stress-strain and relaxation experiments were made using a computer programmable dynamometer (Lloyd LR5K), we obtained the tenacity, extension at break, work at break, modulus and the tensile curve (NFG 07-002 AFNOR, 1985). Average stress-strain curves were obtained. Next,

Corresponding Author: Samah Maatoug, Textile Research Unit, Ksar Hellal., High Technology Institute, Ksar Hellal, Hadj Ali Soua, 5070 Ksar Hellal, Tunisia Tel: + 216 73 475 900 Fax: + 216 73 475 163

Table 1: Test conditions for stress-strain and relaxation trials

Test conditions	Test settings	
	Starch films	yarns
Specimen effective length (size)	1×10 mm²	500 mm
Deformation rate	50 mm mn⁻¹	150 mm mn⁻¹
Pre-tension	-	0.5 cN tex⁻¹
Sample number	15	50

the model equations were calculated using the iteration procedures included in the nonlinear regression methods. Finally, we calculated the model's parameters.

RESULTS AND DISCUSSION

When yarns are mechanically deformed, distortions at the macroscopic level produce changes at the molecular level. Bonds and interactions between components of the macromolecules forming the fibers become stressed. Three regions can be defined according to the stress-strain curve shape: the initial region, the yield region and the strengthening zone (Vangheluwe, 1992b; Ward and Hadley, 1993). For small strain, when mechanically, a yarn acts as a linear viscoelastic material; the model of the polymer is an extension of a standard linear solid with a distribution of relaxation times. It reflects more of a mechanical behavior approximating linear viscoelasticity called pre-yield region. When higher strains are considered, elongation increases rapidly but without notable increases in stress; this part of the curve is called the yield region. Stretching upward, the post-yield region can be reached, where load and extension are again proportional. Yarn breakage occurs mainly in this region. Depending on the strain, the material behaves successively like a crystallized solid in the pre-yield region, like an amorphous solid or a liquid in the yield region, where it is said to have a plastic-like response and again like a solid in the post-yield region (Vangheluwe, 1992b). All the rheologicol models should include terms that define the three regions.

The sized yarn is composed of two phases: the unsized yarn and the sizing film. Therefore, the mechanical behaviour of each phase plays an important role in the whole mechanical behaviour of the final material. The rheological model of the sized yarn can be justified while taking account of the two models of the unsized yarn and the sizing film.

Theoretical model for stress-strain curves of sized films

Starch film preparation: Sizing films were prepared by casting employing maize starch. Filmogenic solution are poured onto the Petri disks and then dried. The result is translucent films, which could be easily removed from the plate. The constituents are constantly agitated until the agglutination temperature 65-70°C is reached, when reaching this temperature; we heated it ten additional minutes until to reached 90°C. The conditioned film is then placed between paper sheets with millimeter graduation and cut into strips of 1mm wide.

Model-fitting: Viscoelastic modeling based on several mechanistic models (Maxwell, Kelvin voigt, ...) for fitting experimental data of tensile tests are investigated to prove better the viscoelastic properties of sizing films (Fig. 2): the model equations were calculated using the iteration procedures included in the nonlinear regression methods.

Fitting aptness can be assessed by comparing the coefficient estimation R^2. The higher the coefficient (near to 1), the better the fit is obtained.

The Zener's model (Fig. 1) is mathematically described by modified Kelvin-voigt's equation, which yields to the following expression,

$$\sigma(\varepsilon) = A + B \cdot \varepsilon - C(\exp(-D\varepsilon)) \qquad (1)$$

Figure 2 shows one example of the fits obtained.

Table 2 shows a classification of the ratio and the determination coefficients obtained by the different models in sizing film. The R^2 value of 0.998, that the Zener's model gave good fits in sizing film.

Theoretical model for stress-strain curves of unsized yarns: Viscoelastic modeling based on several mechanistic models (Manich, vanghluwe, Zurek, modified Vangheluwe's model and modified Zurek's model, ...) for fitting experimental data of tensile tests are investigated to prove better the viscoelastic properties of yarns.

Table 2 and 3 shows a classification of the ratios and the determination coefficients obtained by the two different models in sized and unsized yarns, which gave the better curves fitting. Final classification of the model aptness is given on the basis of these informations. In general, Manich's model gave the best fits in unsized yarn.

Using Vangheluwe's model, Manich (Vangheluwe, 1992a) developed a new model by including exponents to transform linear elements into non-linear elements. So the equation can be expressed as follows:

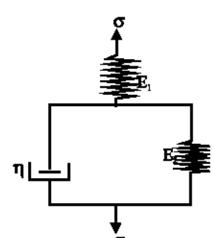

Fig. 1: Zener's model

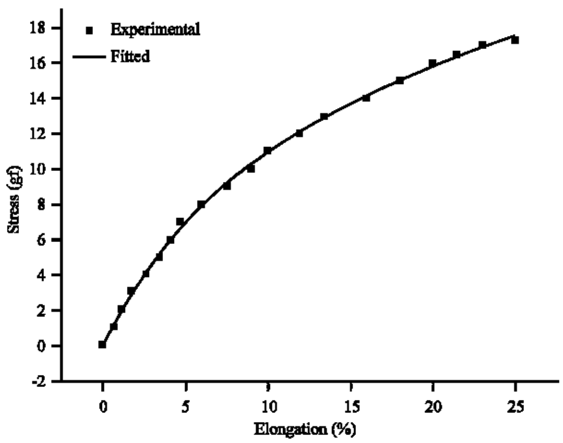

Fig. 2: Nonlinear fitting sizing film tensile curve

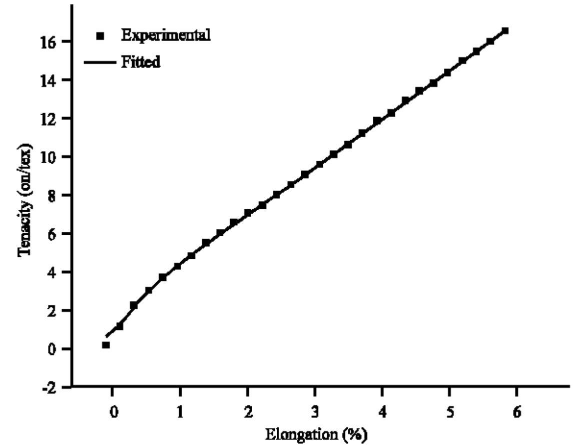

Fig. 3: Nonlinear fitting unsized yarn tensile curve

Table 2: Model's parameters sizing film

Zener's model	
A	10.134
B	0.310
C	10.059
D	0.151
R^2	0.998

Table 3: Unsized yarn manich model's parameters

Parameters	Values
A	1.378
B	2.589
C	1.748
D	2.243
E	1.057
R^2	0.999

$$\sigma = \sigma_0 + A\left(1 - \exp\left(-B\varepsilon^{D}\right)\right) + C\varepsilon^{E} \quad (2)$$

Figure 3 shows one of the fits obtained. The yield region begins above A, which represents the tenacity where the slippage between fibers occurs. The speed of the relative fiber slippage is directly related to B, which is the inverse of relaxation time. The stiffness of the post-yield region is proportional to C. the Maxwell element in the Manich's model expresses the viscoelastic behavior of the unsized yarn.

According to experimental fitting, the total stress on the unsized yarn would be,

$$\sigma = 0.5 + 1.378\left(1 - \exp\left(-2.589\varepsilon^{2.243}\right)\right) + 1.748\varepsilon^{1.057} \quad (3)$$

Theoretical model for stress-strain curves of sized yarns: The tenacity at break of sized yarn increases when sizing and elongation at break decreases owing to compactness of fibrous structure.

According to Eq. 2, the yield region of the curve represents the linear dependence of tenacity versus elongation in the yield region of the curve.

According to R^2 value (0.99), modified Zurek's model adjusts well the experimental tensile data for sized yarn.

The Zurek's model, as shown in Fig. 4, consists of frictional element T with mass inertia M, in parallel with an element formed by Hook spring E_2 and Newton dashpot of viscosity η, all in series with another Hook spring of modulus E_1.

The model is mathematically described by modified Kelvin-voigt's equation, which yields the following expression:

$$\sigma = A\varepsilon + B\left(1 - \exp\left(-C\varepsilon\right)\right) + D * \exp\left(-C\varepsilon\right) \quad (4)$$

Adding exponents to Zurek's model, we obtain a new model that fits the experimental data better. Thus, the non-linear modification of Zurek's equation is

$$\sigma = A\varepsilon + B\left(1 - \exp\left(-C\varepsilon^{D}\right)\right) + E * \exp\left(-C\varepsilon^{F}\right) \quad (5)$$

Figure 5 gives an example of the modified Zurek's model fitting in sized yarn.

The sized yarn is a composite of the unsized yarn and the sizing film. Therefore, the rheological model of the sized yarn can be justified by taking account of the two models of the unsized yarn and the sizing film. The first difference between the model of manich, which describes the unsized yarn and that of zurek, which describes sized yarn, is the Hook spring in series with a formed group of Newton dashpot and other springs: This hook spring comes from combining the size to the unsized yarn.

According to experimental fitting (Table 4), the total stress on the sized yarn would be,

$$\sigma = 3.313\varepsilon + 2.206\left(1 - \exp\left(-3.185\varepsilon^{0.875}\right)\right) + 0.061 * \exp\left(-3.185\varepsilon^{2.041}\right) \quad (6)$$

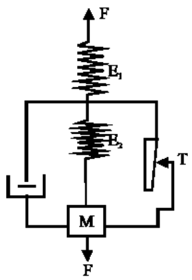

Fig. 4: Zurek's model

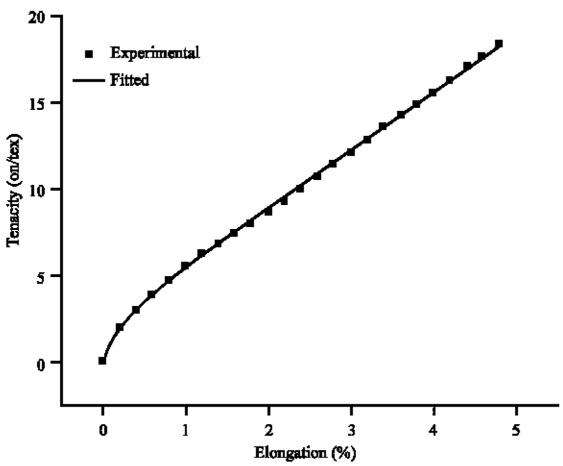

Fig. 5: Nonlinear fitting sized yarn tensile curve

Table 4: Sized yarn modified zurek model's parameters

Parameters	Values
A	3.313
B	2.206
C	3.185
D	0.875
E	0.061
F	2.041
R^2	0.999

CONCLUSIONS

The viscoelastic models used for tensile curves fit of yarns give good results. Bearing in mind the very high values of coefficient ratios R^2, the modified Zurek model yields to the best results for sized yarn combination fitting. The sized yarn is a composite of the unsized yarn and the sizing film, the rheological model of the sized yarn can be justified by taking account of the two models of the unsized yarn and the sizing film.

The best viscoelastic model to explain the load-elongation curve shapes is different in the case of the unsized yarn (manich's model) compared with the sized one (zurek's modified model). This is mainly attributed to the behavior of sizing film, which is an elastic and viscous polymer. The first difference between the model of manich, which describes the unsized yarn and that of zuek, which describes sized yarn, is the Hook spring in series with a formed group of Newton dashpot and other springs: This hook spring comes from combining the size and the unsized yarn.

Sizing yarn mechanical properties prediction has usually been based on unsized yarn and sizing film properties. The properties of yarn do not remain steady throughout textile manufacturing. They are considerably modified by mechanical, thermal and chemical treatments during textile manufacturing.

REFERENCES

Ghosh, A., S.M. Ishtiaque and R.S. Rengasamy, 2005. Stress-strain characteristics of different spun yarns as a function of strain rate and gauge length. The Textile Institute, pp: 99-104.

Manich, A.M., M.H. Ussman and A. Barella, 1990. Viscoelastic behavior of polypropylene fibers. Textile Res. J., 69: 325-330.

Nachane, R.P. and V. Sundaram, 1995a. Analysis of relaxation phenomena in textile fibres. Part I: Stress relaxation. J. Text Inst., 86: T10-19.

Nachane, R.P. and V. Sundaram, 1995b. Analysis of relaxation phenomena in textile fibres. Part II: Inverse relaxation. J. Text Inst., 86: T20-32.

NFG 07-002. Paris: AFNOR, 1985. Determination of tensile stress and strain at break, simplified method.

Persoz, B., 1960. Introduction for the rheological study. Dunod, Paris, France.

Ussman, M.H., A.M. Manich, J. Gacén and J. Maillo, 1999. Viscoelastic behavior and microstructural modifications in acrylic fibers and yarns as a function of tensile manufacturing processing conditions. J. Text Inst., 90: T527-540.

Vangheluwe, L., 1992a. Influence of strain rate and yarn number on tensile test results. Textile Res. J., 62: 586-589.

Vangheluwe, L., 1992b. Comments on stress relaxation and tensile modulus of polymeric fibers. Textile Res. J., 62: 306-308.

Vangheluwe, L., 1993. Relaxation and inverse relaxation of yarns after dynamic loading. Textile Res. J., 63: 552-556.

Ward, I.M. and D.M. Hadley, 1993. An introduction to the mechanical properties of solid polymers. John Wiley and Sons, Chichester, UK.