Fengjun Shi

Modeling Stretching-Relaxation Properties of Yarns

School of Civil Engineering and Communication, North China University of Water Resources and Electrical Power,
Zhengzhou, Henan 450011, China,
E-mail: fengjunshi@371.net

Abstract
In this paper, the stretching-stress relaxation properties of polyester/viscose and regenerated bamboo fiber/cotton blended yarns are studied. Based on the Boltzmann superposition principle, the stretching-stress relaxation process of the yarns is analysed using the standard linear solid model. Theoretical equations of the stretching-stress relaxation process are deduced. Stretching-stress relaxation experiments were made under two different conditions, that is, the yarns were stretched to a definite strain at different rates of straining and to different strains at the same strain-rate. Regressive equations of stress relaxation and correlation coefficients of the yarns are calculated. Theoretical expectations display very good agreement with the experimental observations, indicating that the standard linear solid model can be used to describe the stress relaxation properties of yarns under lower strain conditions. It can also be found from the experimental and theoretical results that the higher the strain-rate and larger the maximum strain, the lower the relaxation time.

Key words: *yarn, viscoelasticity, standard linear solid model, stress relaxation.*

The mechanical properties of yarns are time dependent because of the viscoelastic nature of fibre materials. The strain produced by a given applied stress, or the stress resulting from a given strain in the yarns, depend on how long the stress or the strain has been present and on the earlier mechanical history of the yarns. When a yarn is held stretched, the stress in it gradually decays, which may drop to a limiting value or may disappear completely. This phenomenon is known as relaxation [1, 2]. The stress relaxation behaviour of viscoelastic textile yarn is an important physical property as it determines the residual stress of the yarn and has a major influence on its processing and end-use performance, such as residual torque or the snarl of yarns [3] as well as the wrinkle recovery of fabrics [4, 5] and garments. It is also one of the causes of set marks in weaving [6 - 8]. Therefore a study of the stress relaxation behaviour of textile yarns is of practical interest.

As one of the typical exhibitions of viscoelasticity, the relaxation behaviors of textile fibres [9 - 16], yarns [17 - 22] and fabrics [23] have been widely investigated. Among the studies of the relaxation behavior of textile materials, most of the research reports were based on a mechanical model consisting of a series of elements, such as Hook springs,

Newton dashpots, unidirectional friction elements, and inertional elements. Vangheluwe's model [17] consists of a Maxwell's model (a Hooke spring connected in series with a Newton dashpot) in parallel with a nonlinear spring which takes into account the nonlinearity caused in the relaxation and inverse relaxation of yarns after dynamic loading. Based on the principle of Boltgation superposition, L. Chen et al. [18] investigated the stress relaxation of bamboo pulp yarns with different structures using a four-element model which includes two paralleled Maxwell models. To analyse the stress relaxation behaviour of knitted fabrics, M. Matsuo et al. [23] adopted a four-element model with two springs and two dashpots. The theoretical prediction was in good agreement with the experimental results. Zou [21] analysed the stress relaxation property of Vortex spun yarns and compared it with air-jet spun yarn and ring spun yarn using a modified generalised Maxwell model developed by Asma El Oudiani [15]. The model is composed of a two paralleled Voigt element and Maxwell element in series with a Hook spring. H. Liu et al. [22] employed a generalised Maxwell model to describe the viscoelastic characteristic function of individual fibres subject to a given step function of tensile strain. The relaxation modulus of a single spun yarn is modeled in terms of the relaxation modulus of constituent fibres of the yarn. Demidov [24] proposed a version of the mathematical model of the nonlinear-hereditary viscoelasticity of polymer materials which is used to predict strain processes of various complexity, from simple relaxation and simple creep processes to complicated strain recovery processes and reverse relaxation processes with alternating loading and unloading. The models can be used not only to describe the macroscopic mechanical performance but also to analyse the mechanical properties quantitatively [25, 26]. Now they are widely used in the study of the mechanical properties of textile materials.

Relaxation is the reduction of stress with time under a given extension. According to the definition, a step response strain is needed to be served to the specimen to measure the relaxation. However, it always takes a period of time for a tensile tester to stretch a yarn to a given extension. Therefore it is necessary to consider the effect of the stretching process on the relaxation. Hence a standard linear solid model has been used to analyse the relaxation behaviour of yarns in the

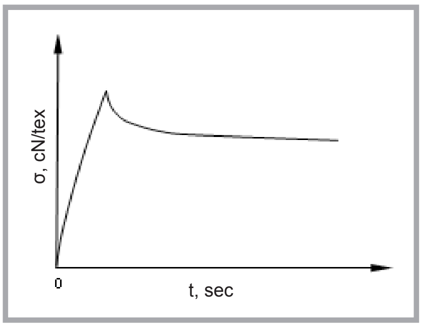

***Figure 1.** Stress relaxation experiment curves of the yarn.*

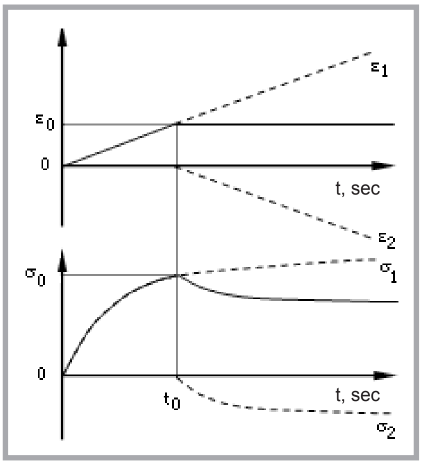

***Figure 2.** Superposition of stress and strain for the stretching-relaxation process.*

stretching-relaxation process in the present work.

Theoretical analysis

When a fibre or a yarn is stretched at a constant rate of straining, an internal stress is set up gradually. When it is stretched to a given strain and held at the same strain, the stress decreases as time passes. This is illustrated in ***Figure 1***, from which it appears that after a rapid initial decay of stress, the rate of decay drops to zero.

In the stretching-relaxation process, the change of strain and stress within the yarn with time is shown in ***Figure 2***. At first, the yarn is stretched under a constant rate of straining k, its strain then increases linearly with time t, that is $\varepsilon_1(t) = kt$, and the stress σ_1 within the yarn increases gradually. When the yarn is stretched to a given strain ε_0 at time t_0, it is constrained to remain at ε_0. Then the relaxation begins and the stress within the yarn decreases as time passes. According to the Boltzmann superposition principle, the stretching-relaxation process is equivalent to the superposition of two strains in which one is increasing at a constant rate of straining k, $\varepsilon_1(t) = kt$, and the other is applied to the yarn for time t_0 and is stretched at the same rate of straining k in the reverse direction, $\varepsilon_2(t) = -k\,(t - t_0)$ $(t \geq t_0)$. Similarly there is also stress $\sigma_2(t)$ corresponding to the strain $\varepsilon_2(t)$, that is, $\varepsilon(t) = \varepsilon_1(t) = kt$ when $t < t_0$, and $\varepsilon(t) = \varepsilon_1(t)+\varepsilon_2(t) = kt - k(t-t_0) = kt_0 = \varepsilon_0$ when $t \geq t_0$. The corresponding internal stress within the yarn produced by $\varepsilon_1(t)$ and $\varepsilon_2(t)$ is $\sigma_1(t)$ and $\sigma_2(t)$. The stress of the yarn is $\sigma(t) = \sigma_1(t)$ when $t < t_0$, and $\sigma(t)$ is the superposition of $\sigma_1(t)$ and $\sigma_2(t)$ when $t \geq t_0$, that is $\sigma(t) = \sigma_1(t) + \sigma_2(t)$.

For convenience of calculation, the stretching-relaxation process is analysed using the standard linear solid model, which consists of a Hook's spring in series with a Voight model in which a Hook's spring and ideal viscous dashpot are in parallel, as shown in ***Figure 3***. If E_1 and E_2 are the elastic modulus of the springs, η is the coefficient of viscosity of the dashpot, and k is the rate of straining, the stress of the yarn in the stretching process can be obtained as ***Equation 1.***

$$\sigma_1(t) = \frac{E_1 E_2}{E_1 + E_2} kt + \frac{E_1^2}{(E_1 + E_2)^2} k\eta\left(1 - e^{-t(E_1+E_2)/\eta}\right) \quad (1)$$

In ***Equation 1***, $\sigma_1(t)$ is the stress produced by $\varepsilon_1(t)$, which can be simplified as ***Equation 2.***

$$\sigma_1(t) = at + b\left(1 - e^{-t/T}\right) \quad (2)$$

where, T is the relaxation time *o*f the yarn, and a & b are constants.

$$T = \frac{\eta}{E_1 + E_2}, \quad a = \frac{E_1 E_2}{E_1 + E_2} k,$$

$$b = \frac{E_1^2}{(E_1 + E_2)^2} k\eta .$$

Similarly the stress $\sigma_2(t)$ produced by $\varepsilon_2(t)$ can *b*e expressed as

Table 1. Mechanical property of blended yarns.

Specimen	Tenacity, cN·tex-1		Breaking elongation, %		Initial modulus, cN·tex-1		Work of rupture, mJ	
	Average	CV%	Average	CV%	Average	CV%	Average	CV%
R.B/C	9.29	3.3	10.96	7.1	134.67	2.3	121.14	9.9
P/V	18.85	13	10.02	9.8	159.19	1.9	73.33	20

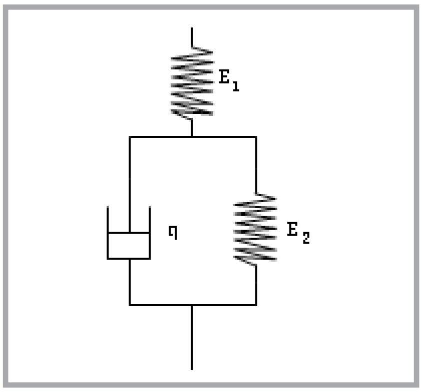

***Figure 3.** Standard linear solid model.*

$$\sigma_2(t) = a(t - t_0) + b\left(1 - e^{-(t-t_0)/T}\right) \quad (3)$$

Then the relaxation stress of the yarn can be derived by superimposing $\sigma_1(t)$ and $\sigma_2(t)$ as

$$\sigma(t) = \sigma_1(t) - \sigma_2(t) = $$
$$= at + b\left(1 - e^{-t/T}\right) - \left[a(t - t_0) + b\left(1 - e^{-(t-t_0)/T}\right)\right] = \quad (4)$$
$$= at_0 - b\left(e^{-t/T} - e^{-(t-t_0)/T}\right)$$

Experimental conditions

The test samples were 36.4 tex regenerated bamboo/cotton (R.B/C) 30/70 and 14.5 tex polyester/viscose (P/V) 50/50 blended yarns. The mechanical properties of the regenerated bamboo/cotton and polyester/viscose blended yarns are listed in ***Table 1***. The stretching-relaxation tests were carried out on a 5582 Instron Tester under different rates of straining and five different maximum strains. The five strain-rates were 5, 10, 20, 30 and 40%/min, and the five maximum strains were 0.5, 1, 2, 3 and 4%. According to ISO 2062, the pre-tension was 0.5 cN/tex, under which the yarn became straight but with no elongation. The gauge length was 500 mm. All the samples were preconditioned and all experiments were tested at constant ambient conditions (60 ± 5% RH, 20 ± 1 °C). Five specimens were tested in each case.

Results and discussion

Stretching-relaxation tests were made under different strain-rates and different maximum strains using an 5582 Instron Tester. Stretching-relaxation curves for the regenerated bamboo/cotton and polyester/viscose blended yarns under different strain-rates are illustrated in

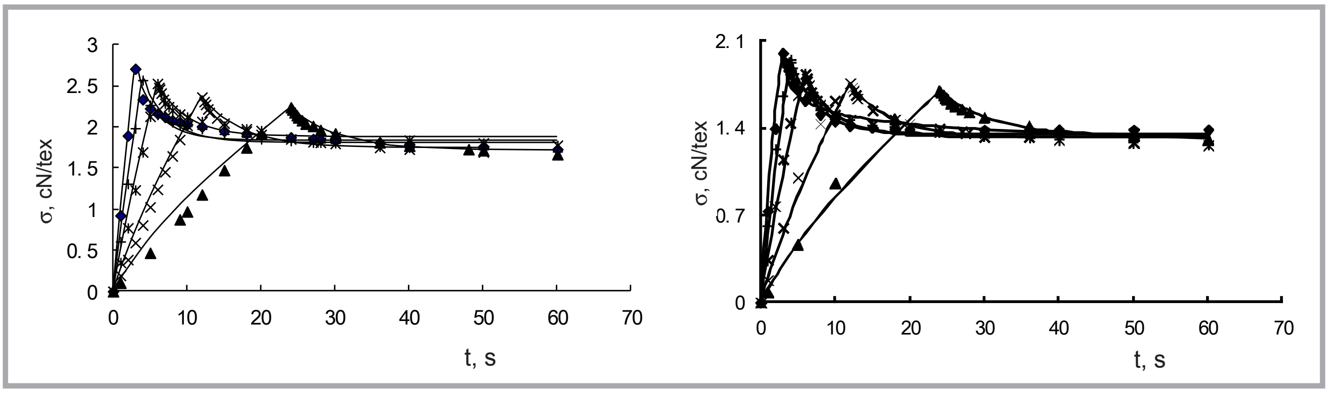

Figure 4. Relaxation curves for R.B/C (a) and P/V (b) blended yarns under different strain-rates: ▲ *5%/min,* × *10%/min,* ✳ *20%/min,* + *30%/min,* ◆ *40%/min.*

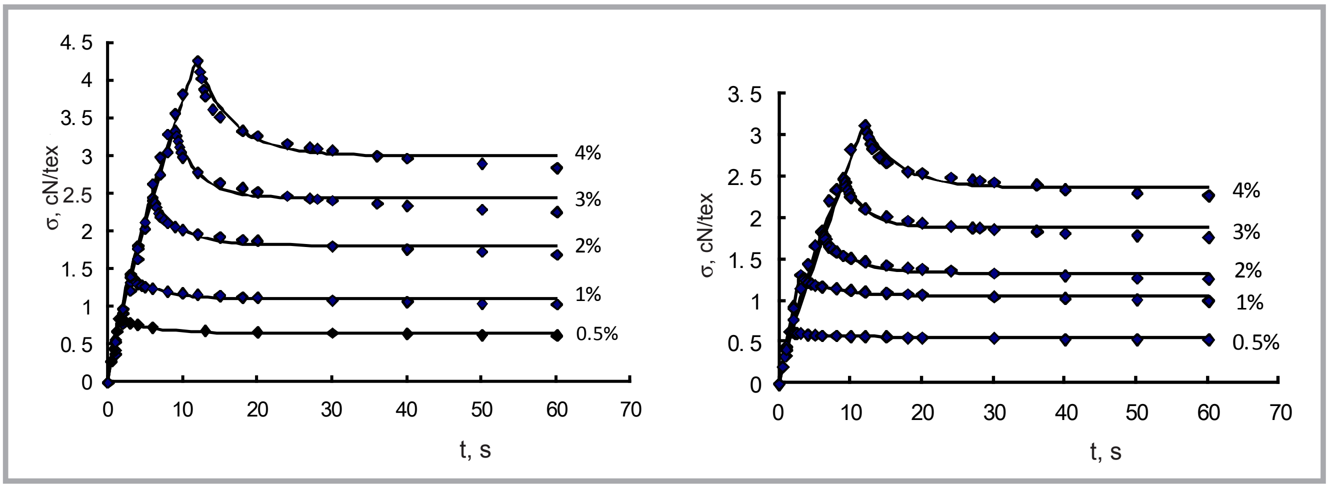

Figure 5. *Relaxation curves for R.B/C (a) and P/V (b) blended yarns under different maximum strains.*

Figure 4. And stretching-relaxation curves for the blended yarns under different maximum strains are illustrated in ***Figure 5***. According to ***Equation 4*** above, regression equations of the stretching--relaxation curves were calculated based on the experimental results. Regression equations for the regenerated bamboo/cotton and polyester/viscose blended yarns under different strain-rates are listed in ***Tables 2*** and ***3*** (see page 54). And regression equations for the regenerated bamboo/cotton and polyester/viscose blended yarns under different maximum strains are listed in ***Tables 4*** and ***5*** (see page 54). The calculated stretching-relaxation curves of the regenerated bamboo/cotton and polyester/viscose blended yarns are depicted in ***Figures 4 - 5***. It can be concluded that all the theoretical calculations and experimental observations demonstrate good agreement.

Effect of the rate of straining on the stretching-relaxation

Figure 4 are stretching-relaxation curves of regenerated bamboo/cotton and polyester/viscose blended yarns which are stretched to a certain strain under different strain-rates. All the curves exhibit obvious consistency. At the beginning of relaxation, the stress decreases rapidly as the relaxation time increases. Then the variation in stress decreases as time passes, and the relaxation stress almost does not change after a period of time.

It can also be noted from ***Figure 4*** that the higher the strain-rate, the larger the stress within the yarn. And the reduction in relaxation stress is also quicker for a higher rate of straining. The relaxation curves for different strain-rates approach and almost overlap as time elapses. From the regression equations in ***Tables 2*** and ***3***, it can be found that the relaxation time T is smaller for a higher rate of straining, that is, the relaxation phenomenon can be more clearly observed under a higher rate of straining.

Effect of maximum strain on stretching-relaxation

Figures 5 are stretching-relaxation curves of the regenerated bamboo/cotton and polyester/viscose blended yarns stretched to different strains at the same rate. It can be found that the theoretical curves match the experimental data very well at low strain, indicating that the mechanical behaviour of the yarns is linear viscoelastic at a low strain condition. However, the deviation between the calculation and observation under high strain increases as the time progresses, which is because plastic deformation occurring more or less at a high strain condition will reduce the relaxation stress. It can also be observed from the equations in ***Tables 4*** and ***5*** that the relaxation time T decreases with an increase in the maximum strain ε_0. It can be concluded that the relaxation of the yarn is more obvious under a larger maximum strain.

Conclusions

Based on the Boltzmann superposition principle, the stretching-stress relaxation process of yarns is analysed using the standard linear solid model. Theoretical equations of the stretching-stress

Table 2. Fitted stretching-relaxation equations for R.B/C blended yarns under different strain-rates.

Strain rate, %/min	Fitted stretching equation	Fitted relaxation equation	Correlation coefficient
5	$t < 24$ $\sigma = 0.0715t + 0.5373 \times (1 - e^{-t/6.46})$	$t > 24$ $\sigma = 0.0715 \times 24 - 0.5373 \times (e^{-t/6.46} - e^{-(t - 24)/6.46})$	0.9969
10	$t < 12$ $\sigma = 0.1452t + 0.7023 \times (1 - e^{-t/5.50})$	$t < 12$ $\sigma = 0.1452 \times 12 - 0.7023 \times (e^{-t/5.50} - e^{-(t - 12)/5.50})$	0.9931
20	$t < 6$ $\sigma = 0.3134t + 0.843 \times (1 - e^{-t/4.07})$	$t < 6$ $\sigma = 0.3134 \times 6 - 0.843 \times (e^{-t/4.07} - e^{-(t - 6)/4.07})$	0.9896
30	$t < 4$ $\sigma = 0.4522t + 1.1407 \times (1 - e^{-t/3.62})$	$t < 4$ $\sigma = 0.4522 \times 4 - 1.1407 \times (e^{-t/3.62} - e^{-(t - 4)/3.62})$	0.9884
40	$t < 3$ $\sigma = 0.6104t + 1.417 \times (1 - e^{-t/3.10})$	$t < 3$ $\sigma = 0.6104 \times 3 - 1.417 \times (e^{-t/3.10} - e^{-(t - 3)/3.10})$	0.9874

Table 3. Fitted stretching-relaxation equations for P/V blended yarns under different strain-rates.

Strain rate, %/min	Fitted stretching equation	Fitted relaxation equation	Correlation coefficient
5	$t < 24$ $\sigma = 0.0555t + 0.3776 \times (1 - e^{-t/7.16})$	$t > 24$ $\sigma = 0.0555 \times 24 - 0.3776 \times (e^{-t/7.16} - e^{-(t - 24)/7.16})$	0.9965
10	$t < 12$ $\sigma = 0.1109t + 0.4859 \times (1 - e^{-t/5.42})$	$t < 12$ $\sigma = 0.1109 \times 12 - 0.4859 \times (e^{-t/5.42} - e^{-(t - 12)/5.42})$	0.9916
20	$t < 6$ $\sigma = 0.2216t + 0.6415 \times (1 - e^{-t/3.89})$	$t < 6$ $\sigma = 0.2216 \times 6 - 0.6415 \times (e^{-t/3.89} - e^{-(t - 6)/3.89})$	0.9916
30	$t < 4$ $\sigma = 0.3376t + 0.9027 \times (1 - e^{-t/3.65})$	$t < 4$ $\sigma = 0.3376 \times 4 - 0.9027 \times (e^{-t/3.65} - e^{-(t - 4)/3.65})$	0.9891
40	$t < 3$ $\sigma = 0.4619t + 0.9935 \times (1 - e^{-t/3.12})$	$t < 3$ $\sigma = 0.4619 \times 3 - 0.9935 \times (e^{-t/3.12} - e^{-(t - 3)/3.12})$	0.9884

Table 4. Fitted stretching-relaxation equations for R.B/C blended yarns under different maximum strains.

Maximum strain, %	Fitted equation of extension	Fitted relaxation equation	Correlation coefficient
0.5	$t < 1.5$ $\sigma = 0.4367t + 0.6007 \times (1 - e^{-t/3.87})$	$t > 1.5$ $\sigma = 0.4367 \times 1.5 - 0.6007 \times (e^{-t/3.87} - e^{-(t - 1.5)/3.87})$	0.9972
1.0	$t < 3$ $\sigma = 0.3627t + 0.6176 \times (1 - e^{-t/3.77})$	$t < 3$ $\sigma = 0.3627 \times 3 - 0.6176 \times (e^{-t/3.77} - e^{-(t - 3)/3.77})$	0.9954
2.0	$t < 6$ $\sigma = 0.3009t + 0.7907 \times (1 - e^{-t/3.69})$	$t < 6$ $\sigma = 0.3009 \times 6 - 0.7907 \times (e^{-t/3.69} - e^{-(t - 6)/3.69})$	0.9920
3.0	$t < 9$ $\sigma = 0.2701t + 0.9548 \times (1 - e^{-t/3.16})$	$t < 9$ $\sigma = 0.2701 \times 9 - 0.9548 \times (e^{-t/3.16} - e^{-(t - 9)/3.16})$	0.9915
4.0	$t < 12$ $\sigma = 0.2492t + 1.3625 \times (1 - e^{-t/4.57})$	$t < 12$ $\sigma = 0.2492 \times 12 - 1.3625 \times (e^{-t/4.57} - e^{-(t - 12)/4.57})$	0.9872

Table 5. Fitted stretching-relaxation equations for P/V blended yarns under different maximum strains.

Maximum strain, %	Fitted equation of extension	Fitted relaxation equation	Correlation coefficient
0.5	$t < 1.5$ $\sigma = 0.3677t + 0.2781 \times (1 - e^{-t/4.71})$	$t > 1.5$ $\sigma = 0.3677 \times 1.5 - 0.6007 \times (e^{-t/4.71} - e^{-(t - 1.5)/4.71})$	0.9972
1.0	$t < 3$ $\sigma = 0.3489t + 0.5022 \times (1 - e^{-t/4.04})$	$t < 3$ $\sigma = 0.3489 \times 3 - 0.5022 \times (e^{-t/4.04} - e^{-(t - 3)/4.04})$	0.9954
2.0	$t < 6$ $\sigma = 0.2745t + 0.7491 \times (1 - e^{-t/3.81})$	$t < 6$ $\sigma = 0.2745 \times 6 - 0.7491 \times (e^{-t/3.81} - e^{-(t - 6)/3.81})$	0.9920
3.0	$t < 9$ $\sigma = 0.2081t + 0.6313 \times (1 - e^{-t/3.15})$	$t < 9$ $\sigma = 0.2081 \times 9 - 0.6313 \times (e^{-t/3.15} - e^{-(t - 9)/3.15})$	0.9915
4.0	$t < 12$ $\sigma = 0.1961t + 0.8166 \times (1 - e^{-t/4.60})$	$t < 12$ $\sigma = 0.1961 \times 12 - 0.8166 \times (e^{-t/4.60} - e^{-(t - 12)/4.60})$	0.9872

relaxation process are deduced. Stress relaxation experiments were made under different rates of straining and different maximum strains for regenerated bamboo fiber/cotton and polyester/viscose blended yarns. The comparison between the theoretical calculations and experimental observations displays very good agreement, indicating that the standard linear solid model can be used to describe the stress relaxation properties of yarns under lower strain conditions. The larger the strain-rate or the maximum strain, the smaller the stress relaxation time for the stretching-relaxation process. The relaxation phenomenon is more obvious under a higher strain rate of straining and larger maximum strain.

Acknowledgement

This research was supported by the Fund for Natural Science of Henan Province (No. 041102000) and Foundermantal Ressearch Programm of Henan Education Adminastration (No. 200410465012).

References

1. Morton WE, Hearle JWS. *Physical Properties of Textile Fibers.* 3rd ed. The Textile Institute, Manchester, 1993, pp. 481-501.
2. Postle R, Carnaby GA, Jong SD. *The Mechanics of Wool Structures*. Ellis Horwood Limited, Chichester, 1988.
3. Tao XM, Lo WK, Lau YM. Torque-balanced Singles Knitting Yarns Spun by Unconventional Systems. 1. Cotton Rotor Spun Yarn. *Textile Research Journal* 1997; 67(10): 739–746.
4. Chapman BM. Model for Crease Recovery of Fabrics. *Textile Research Journal* 1974; 44(7): 531–538.
5. Hu J, Shi F. Wrinkle Recovery Angle of Woven Fabrics. *Textile Asia* 1999; 30(4): 68-70.
6. Manich AM, Decastellar MD. Elastic Recovery and Inverse Relaxation of Polyester Staple Fiber Rotor Spun Yarns. *Textile Research Journal* 1992; 62(4): 196–199.
7. Nachane RP, Hussain GFS, Iyer KRK. Inverse Relaxation Stress Recovery in Cotton Fibers and Yarn. *Textile Research Journal* 1982; 52(7): 483–484.
8. Nachane RP, Hussain GFS, Patel GS, Iyer KRK. Inverse Relaxation in Spun Yarns. *J. Appl. Polym. Sci.* 1986; 31(4): 1101–1110.
9. Fancey KS. A Mechanical Model for Creep, Recovery and Stress Relaxation in Polymeric Materials. *J. Mater. Sci.* 2005; 40(18): 4827–4831.
10. Kothari VK, Rajkhowa R, Gupta VB. Stress Relaxation and Inverse Stress Relaxation in Silk Fibers. *J. Appl. Polym. Sci.* 2001; 82(5): 1147–1154.
11. Nachane RP, Sundaram V. Analysis of Relaxation Phenomena in Textile Fibers. 2. Inverse Relaxation. *Journal of the Textile Institute* 1995; 86(1): 20–32 .
12. Nachane RP, Sundaram V. Analysis of Relaxation Phenomena in Textile Fibers. 1. Stress–Relaxation. *Journal of the Textile Institute* 1995; 86(1): 10–19.
13. Liu HL, Yu WD, Jin HB. Modeling the Stress– Relaxation Behavior of Wool

Fibers. *J. Appl. Polym. Sci.* 2008; 110(4): 2078–2084.
14. Gupta VB, Rao DR. Stress–Relaxation Studies on Wool Fibers. *J. Appl. Polym. Sci.* 1992; 45(2): 253–263.
15. Asma El Oudiani, Ben Sghaier, Slah M'sahli, Yassin Chaabouni and Faouzi Sakli. Elastic Recovery and Viscoelastic Behavior of Agave americana L. Fibers. *Text Res J* 2009; 79: 166-178.
16. Fancey KS. A Mechanical Model for Creep, Recovery and Stress Relaxation in Polymeric Materials. *J Mater Sci* 2005; 40(18): 4827–4831.
17. Vangheluwe L. Relaxation and Inverse Relaxation of Yarns After Dynamic Loading. *Text Res J* 1993; 63(9): 552–556.
18. Chen Lingyan Wang, Ni Yu, Jianyong, Cheng Longdi. Stress relaxation of bamboo pulp yarns with different structures (in Chinese). *Journal of Xi'an Polytechnic University* 2010; 24; 1: 1-4.
19. Manich AM, Maillo J, Cayuela D, Gacen J, de Castellar MD, Ussman M. Effect of the Air-jet and the Falsetwist Texturing Processes on the Stress–Relaxation of Polyamide 6.6 Yarns. *J Appl Polym Sci* 2007; 105(5): 2482–2487.
20. Manich AM, Marino PN, De Castellar MD, Saldivia M, Sauri RM. Viscoelastic Modeling of Natural and Synthetic Textile Yarns. *J Appl Polym Sci* 2000; 76(14): 2062–2067.
21. Zou ZY. Study of the Stress Relaxation Property of Vortex Spun Yarn in Comparison with Air-jet Spun Yarn and Ring Spun Yarn. *Fibres & Textiles in Eastern Europe* 2012; 20; 1(90): 28-32.
22. Liu H, Tao XM, Choi KF, Xu BG. Analysis of the Relaxation Modulus of Spun Yarns. *Text Res J* 2010; 80(5): 403–410.
23. Masaru Matsuo, Tomoko Yamada, Noriko Ito. Stress Relaxation Behavior of Knitted Fabrics under Uniaxial and Strip Biaxial Excitation as Estimated by Corresponding Principle between Elastic and Visco-Elastic Bodies. *Textile Research Journal* 2006; 76: 465-477.
24. Demidov AV, Makarov AG, Stalevich AM. A version of modeling of nonlinear-hereditary viscoelasticity of polymer materials. *Mechanics of Solids* 2009; 44; 1: 122-130.
25. Serwatka A, Bruniaux P, Frydrych I. New Approach to Modeling the Stress-Strain Curve of Linear Textile Products. Part 1–Theoretical Considerations. *Fibres & Textiles in Eastern Europe* 2006; 14, 1(55): 30-35.
26. Serwatka A, Bruniaux P, Frydrych I. Modeling the Stress-strain Curve of Textile Products. Part 2 – Simulation of Real Stress-strain Curves. *Fibres & Textiles in Eastern Europe* 2007; 15, 3(62): 60–62.

Received 03.10.2011 Reviewed 14.03.2012