

# Rheological Modeling of the Dorlastan Core Spun Yarns for Various Dorlastan Drafts and Yarn Counts

Helali H\*, Babay Dhouib A, Msahli S and Cheikhrouhou M

Laboratory of Textile Engineering, University of Monastir, Tunisia

## Abstract

The mechanical behaviour of the Dorlastan® core spun yarns having different counts (100, 50, 33.33 and 25 tex) and various elastane drafts is modeled in this paper. The theoretical analysis is based on the response of the elastic core spun yarn to the tensile and the relaxation tests at different strain levels. These tests have permitted us to identify the non linear viscoelastic behaviour of the Dorlastan® core spun yarn.

Analogical approach is employed to propose the rheological model describing the mechanical behaviour of the elastic core spun yarns. Comparing with the experimental data, the theoretical model gives a reasonably accurate prediction of the mechanical behaviour of the elastic core spun yarns for both tensile and relaxation tests.

**Keywords:** Dorlastan draft; Viscoelastic behavior; Rheological model; Tensile test

## Notation

- $\epsilon$ : Deformation
- $\epsilon_p$ : Deformation corresponding to constraint Threshold
- $D_r$ : Dorlastan draft
- $\tau$ : Tenacity
- $\sigma$ : Constraint
- $\sigma_0$ : Pretension
- $E_c$ : Elasticity modulus of the core
- $\eta_s$ : viscosity modulus of the sheath
- $E_{ve}$ : Elasticity modulus of nonlinear viscoelastic zone
- $\eta_{ve}$ : viscosity modulus of nonlinear viscoelastic zone
- C: Coefficient of non linear spring
- $E_{vp}$ : Elasticity modulus of viscoelastoplastic zone
- $\eta_{vp}$ : viscosity modulus of nonlinear viscoelastoplastic zone
- S: Constraint threshold
- $Y_c$ : Yarn count
- $D_c$ : Dorlastan count

## Introduction

The mechanical properties of yarns have a considerable effect on the processing behaviour and the performance characteristics of both yarns and fabrics. In many applications, one of the most important properties of spun yarns is their tensile characteristics. However, the tensile properties of yarns influence directly their strength during the various stages of manufacturing. The research on the mechanical behaviour of textile yarns dates back to 200 years ago [1]. Several authors have studied the theoretical stress-strain behaviour of yarns. Ghosh has presented the modified Vangluwe model to identify the behaviour of classic, open-end, air jet, and the twisted threads in tensile tests [2]. Moreover, Ussman has proposed the Vangluwe model to describe the viscoelastic behaviour of open-end and classic yarns with

a weak error [3]. Also, Vangheluwe has presented an extension of the nonlinear Maxwell model to describe the relaxation behaviour of warp yarns following the cyclic tests [4]. Furthermore, Maatoug has analyzed the application of one of the most suitable model to characterize the viscoelastic properties of sizing yarns [5]. In addition, Ben Aamar has investigated the mechanical behaviour of open end and ring spun yarns under various levels of strain by using only their technical parameters [6].

However, a very few authors have interested in the modeling of the core spun yarns. The study done by Yang has modeled theoretically the core-sheath structuring effect, using a spring and damper as mechanical elements [7].

In earlier study of the effect of the elastane draft on the rheological modeling of the elastic core spun yarn, the mechanical behaviour of elastic core spun yarns was identified by a rheological modelling on the basis on pre-existent phenomenological models [8].

In the present study, we are interested, in the first part, in the identification of the nonlinear viscoelastic behaviour of the Dorlastan core spun yarn on the basis of the characteristic tests. Then, we will develop an analytical model by using the rheological approach.

## Material and Methods

The experimental evaluation of the theory was made using elastic core spun yarns that are made of Dorlastan® filament core which is covered with cotton fibers.

Dorlastan® filaments used in this study as core are characterised by a very good extensibility that ranges between 400 and 550% and a poor tenacity [9].

**\*Corresponding author:** Helali H, Laboratory of Textile Engineering, University of Monastir, Tunisia, E-mail: [turkihouda@yahoo.fr](mailto:turkihouda@yahoo.fr)

**Received** December 15, 2012; **Accepted** January 11, 2013; **Published** January 19, 2013

**Citation:** Helali H, Babay Dhouib A, Msahli S, Cheikhrouhou M (2013) Rheological Modeling of the Dorlastan Core Spun Yarns for Various Dorlastan Drafts and Yarn Counts. J Textile Sci Eng 3: 127. doi:10.4172/2165-8064.1000127

**Copyright:** © 2013 Helali H, et al. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

The physical parameters of the cotton fibers are listed in table 1.

The Dorlastan® core spun yarns are obtained with a core-spinning process [10] that allows an automatic insertion of the elastane with different percentages.

Dorlastan count 156, 78 and 44 dtex are used respectively for yarn counts 100, 50, 33.33 and 25 tex. So the yarns are designated with 100/156, 50/78, 33.33/78, 33.33/44 and 25/44.

The Dorlastan® drafts and pretension values for the yarns 100/156, 50/78, 33.33/78, 33.33/44 and 25/44 are given in table 2.

The characteristic tests used in this study are the tensile test, the relaxation and cyclic test. These tests have been realized by means of a dynamometer of the type LLOYD in a conditioned atmosphere at a temperature of  $20^{\circ}\text{C} \pm 2^{\circ}\text{C}$  and a relative humidity of  $65\% \pm 2\%$  [11].

The length of the test-tube for all tests has been about 500 mm.

For the tensile test, the extension rates are 150, 300 and 500 mm/min.

The cyclic tests and the relaxation tests are carried out with deformation values being equal to 10%, 30%, 50%, 60%, and 90% of the breaking elongation. These tests are carried out for five cycles (the average value is calculated). The time of the relaxation tests is 900 s.

## Results and Discussion

### Characteristic tests

The response of materials to the characterization tests allows classifying them as: rigid, elastic, viscous, plastic and perfectly plastic. To carry out this classification, three principal characteristic tests are distinguished: tensile test, relaxation test and cyclic test [12].

**Tensile test:** Figure 1 presents an example of the tensile curve of the elastic core spun yarn 100/156 with Dorlastan® draft equal to 3.47.

To defined different regions of the tensile curves of the elastic core spun yarn 100/156 with various Dorlastan® drafts, the cord method was used [13]. The curves derived of the tenacity according to deformation were plotted.

Figure 2 presents the cord modulus according to the deformation of the yarn 100/156 with a Dorlastan® draft equal to 3.47.

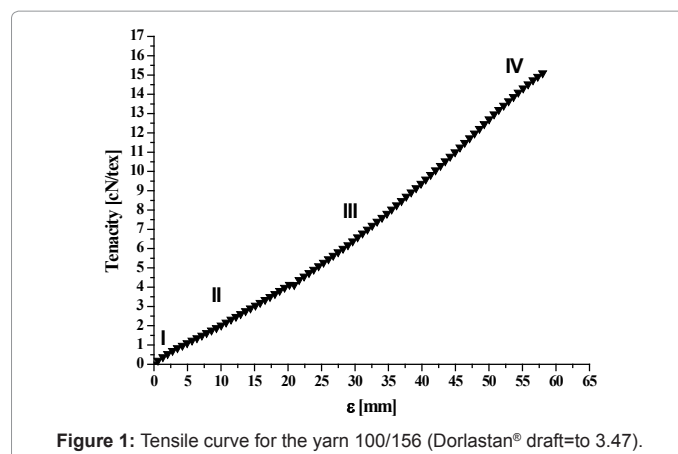
Figure 2 shows the presence of a region for the weak variation of deformation and a minimum which corresponds to the inflection point. This point limits the elastic part of the tensile curve. Furthermore,

Characteristic	Mean value
Micronaire ( $\mu\text{g}/\text{inch}$ )	4.06
Maturity	0.9
UHML (mm)	29.7
Tenacity (cN/tex)	29.3
Elongation (%)	8.36

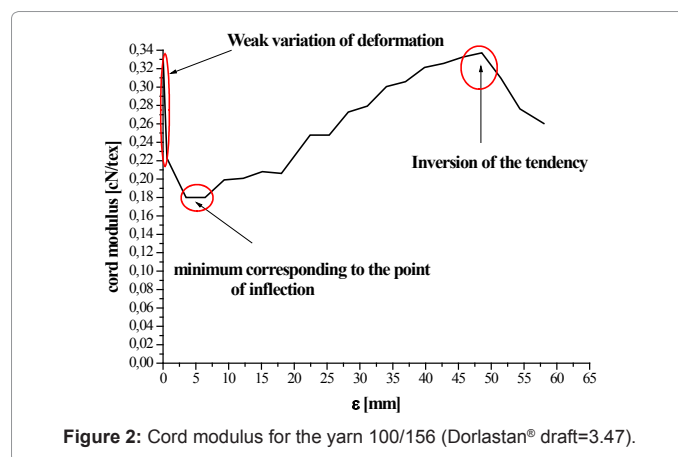
**Table 1:** Cotton fibers properties.

	Extension rates		
	150 mm/min	300 mm/min	500 mm/min
Cord modulus (cN/tex)	0.31	0.32	0.31
Tenacity (cN/tex)	9.18	9.14	9.23
Deformation (mm)	41.78	40.34	43.68

**Table 2:** Tenacity and deformation values corresponding to the cord modulus for various extension rates.



**Figure 1:** Tensile curve for the yarn 100/156 (Dorlastan® draft=to 3.47).



**Figure 2:** Cord modulus for the yarn 100/156 (Dorlastan® draft=3.47).

yarn	100/156								
Dorlastan® ratio[ %]	4	4.5	5	5.5	6	6.5	7	7.5	8
Dorlastan® draft	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
S[cN/tex]	13.13	9.18	11.83	11.96	10.23	12.25	12.59	11.05	10.11
ε <sub>p</sub> [mm]	50.3	41.78	48.1	46.62	46.5	48.7	48.7	48	40.8
yarn	50/78								
Dorlastan® ratio [%]	4	4.5	5	5.5	6	6.5	7	7.5	8
Dorlastan® draft	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
S[cN/tex]	11.34	10.14	8.96	9.92	8.26	8.78	8.04	8.9	9.18
ε <sub>p</sub> [mm]	35.2	30.8	29.8	36.1	30	30	28.4	28.2	26.5
yarn	33.33/44				33.33/78				
Dorlastan® ratio [%]	4	4.5	5	5.5	6	6.5	7	7.5	8
Dorlastan® draft	3.3	2.93	2.64	2.4	3.9	3.6	3.34	3.12	2.93
S[cN/tex]	9.57	9.42	8.61	11.61	11.43	9.66	9.03	6.99	7.26
ε <sub>p</sub> [mm]	29.7	33.7	30.1	34.6	30.3	29.8	29.5	27	24.2
yarn	25/44								
Dorlastan® ratio [%]	4	4.5	5	5.5	6	6.5	7	7.5	8
Dorlastan® draft	4.4	3.91	3.52	3.2	2.93	2.71	2.51	2.35	2.2
S[cN/tex]	8.4	8.52	6.84	7.88	7.4	6.6	8.2	7.16	8.4
ε <sub>p</sub> [mm]	28.6	24.6	22.1	27.1	28.9	24.8	20.8	20.85	26.3

**Table 3:** Constraint thresholds and deformations for different yarns.

the figure 2 shows the presence of a point of change of the tendency which corresponds to the limit of the constraint threshold of the viscoelastoplastic part. Thus, the cord method used for the elastic

core spun yarn 100/156 with various Dorlastan® drafts, shows up the existence of four zones:

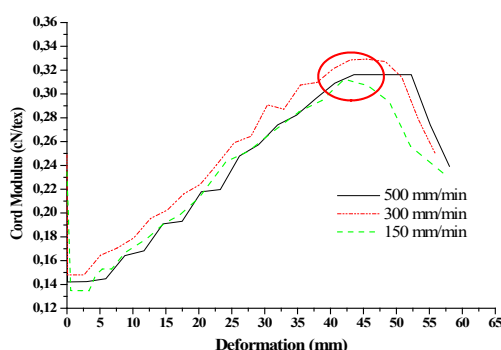
- A first zone of weak deformation which corresponds to the applied pretension
- A second linear portion with a complete recovery
- A third nonlinear zone of viscoelastic deformation. In this region, recovery was partial
- A fourth nonlinear zone of exponential form which starts from a defined constraint threshold. This is the region of high slope leading to the final breakage point.

The same method is used to determine the constraint thresholds concerning the viscoelastoplastic zone for different yarns with various Dorlastan® drafts. The obtained results are presented in table 3.

Furthermore, the cord method [13] is used for the tensile curves carried out at different extension rates equal to 150 mm/min, 300 mm/min and 500 mm/min. the results are presented in figure 3.

As displayed in figure 3, the cord modulus values for different extension rates which are very close. The tenacity and the deformation values corresponding to this modulus are presented in table 4.

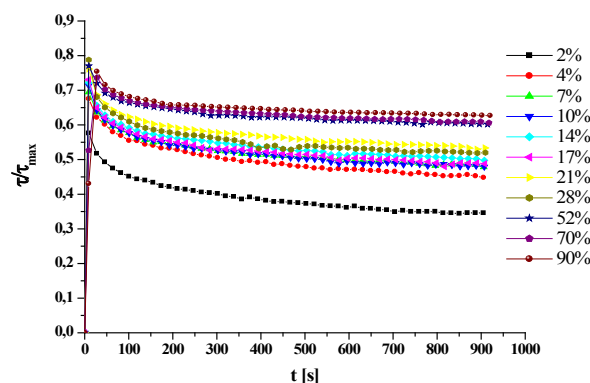
Table 4 shows that the tenacity values corresponding to the cord modulus are very close. Thus, the constraint threshold is almost even for the different extension rates. Hence, the model suggested to describe



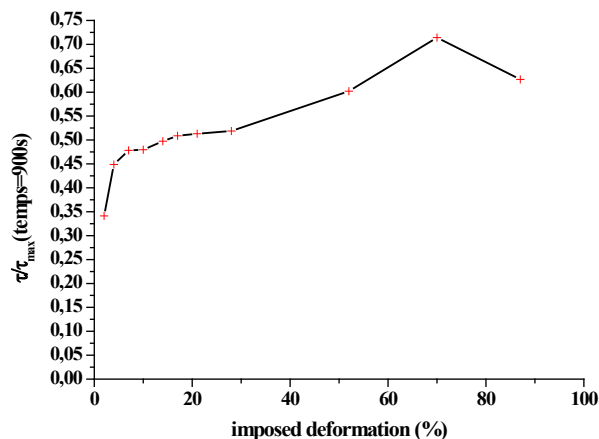
**Figure 3:** Cord Modulus versus deformation for yarn 100/156 (Dorlastan® draft=3.47) at different extension rates.

Yarn count	100 tex								
Dorlastan® count	156								
Dorlastan® draft	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
Pretension (cN/tex)	0.7	0.65	0.64	0.6	0.54	0.52	0.5	0.48	0.43
Yarn count	50 tex								
Dorlastan® count	78								
Dorlastan® draft	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
Pretension (cN/tex)	1.11	0.86	0.81	0.79	0.7	0.69	0.63	0.62	0.51
Yarn count	33.33 tex								
Dorlastan® count	44				78				
Dorlastan® draft	3.3	2.93	2.64	2.4	3.9	3.6	3.34	3.12	2.93
Prétension (cN/tex)	1.15	1.09	1.01	0.97	0.92	0.85	0.79	0.71	0.65
Yarn count	25 tex								
Dorlastan® count	44								
Dorlastan® draft	4.4	3.91	3.52	3.2	2.93	2.71	2.51	2.35	2.2
Pretension (cN/tex)	1.69	1.39	1.34	1.11	1.01	0.93	0.87	0.76	0.79

**Table 4:** The Dorlastan® drafts and pretension values.



**Figure 4:** Relaxation curves of the standardized tenacities for the elastic core spun yarn 100/156.



**Figure 5:** Evolution of the tenacity standardized at time t=900s according to the imposed deformation for the elastic core spun yarn 100/156.

the mechanical behaviour of the Dorlastan® core spun yarns must include a shoe.

**Relaxation test:** Figure 4 presents the curves of the relaxation test standardized by the parameter  $T_{max}$  corresponding to the tenacity reached at the end of the loading for the elastic core spun yarn 100/156 with a Dorlastan® draft equal to 3.47 which meets a Dorlastan® ratio equal to 4.5% [14].

Figure 4 also indicates that the relaxation curves of the standardized tenacities are presented in the form of a curves beam. Thus, the relaxation of the tenacities depends on the imposed deformation level. As a consequence, the elastic core spun yarns present a viscoelastic behaviour.

At the same time, figure 5 develops the tenacity standardized at the relaxation time ( $t=900$  s) which also depends on the imposed deformation level. In fact, the standardized tenacity is weak in the deformation level at the first zone of the tensile curve. It becomes more significant in the second zone. Then, it decreases to reach a minimum starting from the beginning of the third field of deformation level observed during the tensile test. As a result, the elastic core spun yarn presents nonlinear viscoelastic behaviour [14]. So, the model which will describe the mechanical behaviour of the elastic core spun yarn must include a nonlinear component.

**Cyclic test:** Earlier study of the elastic recovery of the elastic core

spun yarn during the cyclic test proved the existence of a constraint threshold (S) from which the elastic core spun yarn keeps a permanent constraint. This factor explains the existence of the fourth zone at the end of the tensile curve and consequently the existence of the shoe in the model suggested to describe the mechanical behaviour of the elastic core spun yarn [15].

## Rheological model

The rheological model proposed to describe the mechanical behavior of the elastic core spun yarn is represented in the following figure 6 and equation 1.

$$\sigma(\varepsilon) = \sigma_0 + E_c * \varepsilon + \eta_s * \dot{\varepsilon}_0 + \eta_{ve} * \dot{\varepsilon}_0 * (1 - \exp(-\frac{E_{ve}}{\eta_{ve}} * (\frac{\varepsilon}{\varepsilon_0}))) + \quad (1)$$

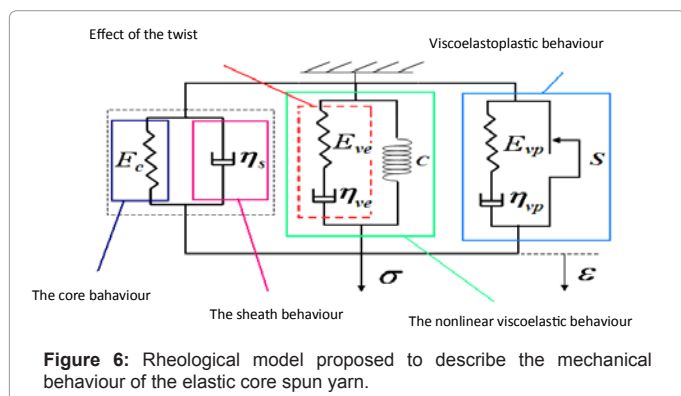
$$C * \varepsilon^n + S + \eta_{vp} * \dot{\varepsilon}_0 * (1 - \exp(-\frac{E_{vp}}{\eta_{vp}} * (\frac{\varepsilon - \varepsilon_p}{\varepsilon_0})))$$

In order to determine the model parameters, the experimental data of the tensile test for the yarn 100/156 having an elastane draft equal to 3.47 was simulated until theoretical curves confounded with the experimental curves and a high determination coefficient  $R^2$  is obtained.

Rheological parameters values and the determination coefficient are given in table 5.

Figure 7 shows the simulation results of the tensile test. As shown in this figure 7, for the comparison of experimental and theoretical data, the proposed model fitted reasonably well with the experimental results seen that  $R^2$  is raised and equal to 0.99 (table 5).

**Validation of the proposed model:** To validate the proposed



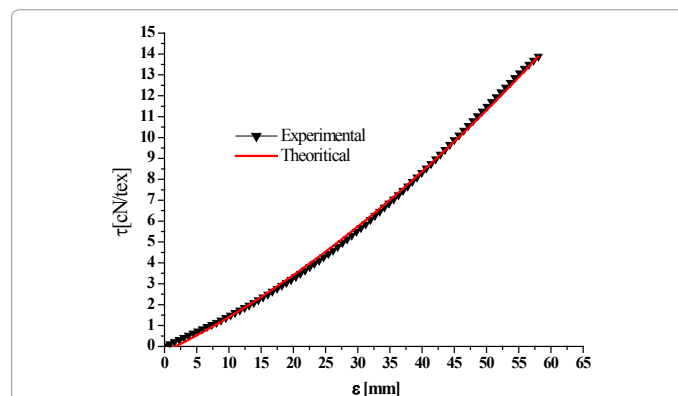
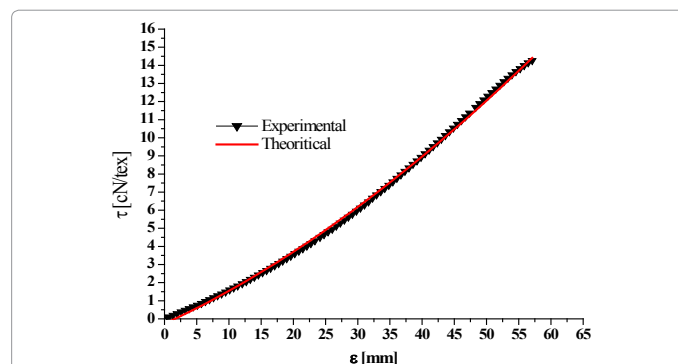
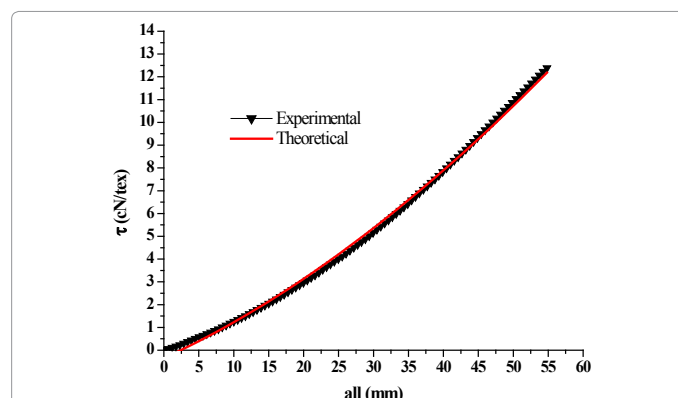
Rheological Parameters	values
$\sigma_0$ [cN/tex]	0.65
$E_c$ [cN/tex]	0.14
$\eta_s$ [cN.S/tex]	3.51
$\eta_{ve}$ [cN.S/tex]	6.14
$E_{ve}$ [cN/tex]	0.02
$C$ [cN/tex]	0.002
$n$	1.89
$S$ [cN/tex]	11.89
$\eta_{vp}$ [cN.S/tex]	0.82
$E_{vp}$ [cN/tex]	0.03
$\varepsilon_p$ [mm]	47.4
$R^2$	0.99

**Table 5:** Rheological parameters and the determination coefficient for the tensile test.

model describing the tensile behaviour of the elastic core spun yarn, the experimental values of the tensile curves were simulated for various extension rates.

The simulation results are presented in the figures 8 and 9.

Figures 7-9 show that the proposed model goes hand in hand with the experimental data of the tensile tests of the yarn 100/156 for different extension rates. Bearing in mind the very high values of the determination coefficient  $R^2$  (table 6), the proposed model yielded the best results for the elastic core spun yarn fitting. Thus, the model



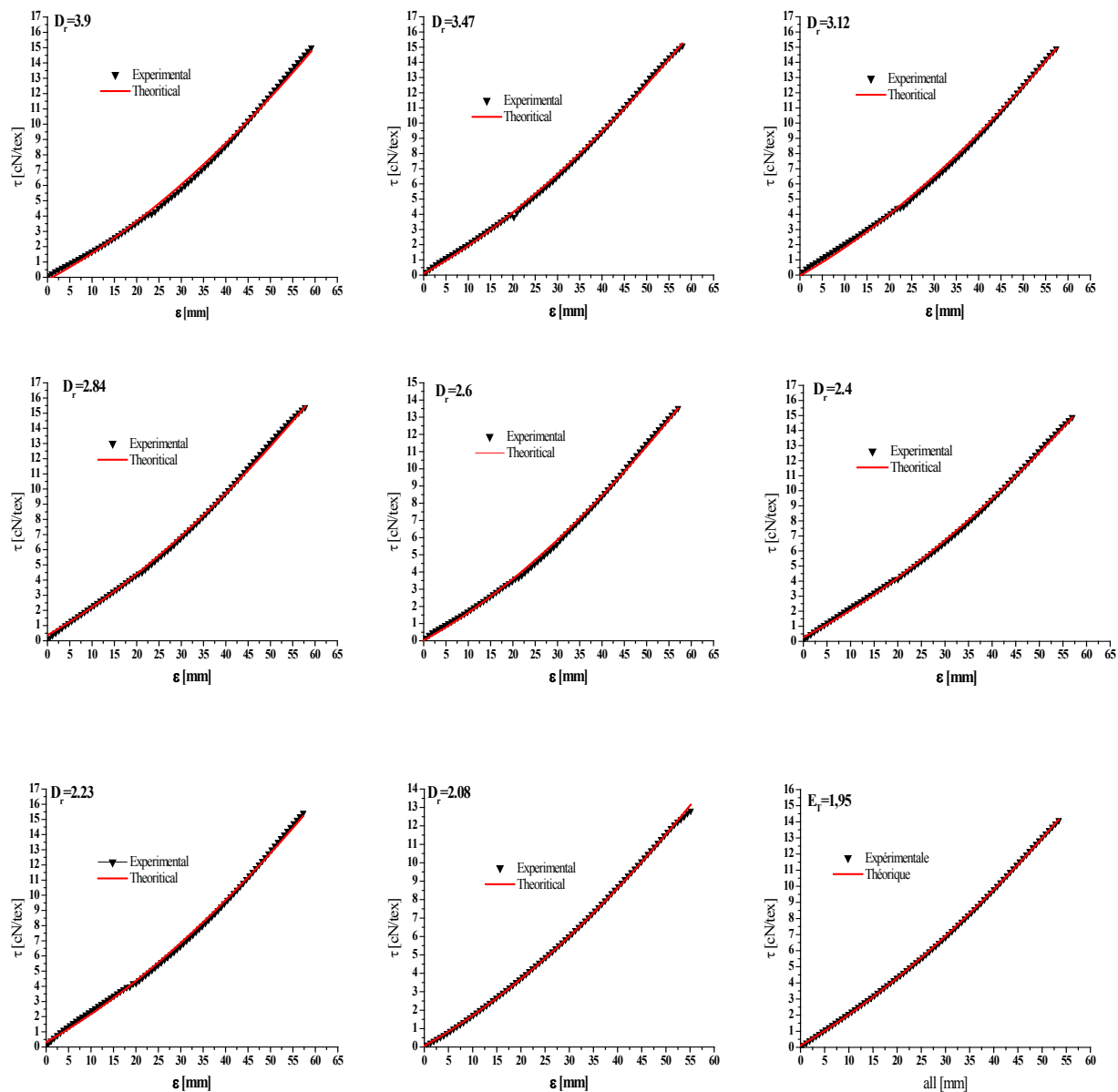


Figure 10: Experimental and theoretical curves of the tensile test for the yarn 100/156 and various Dorlastan® drafts.

Rheological Parameters	Numerical values		
	Extension rate (mm/min)		
	150	300	500
$\sigma_0$ [cN /tex]	0.65	0.65	0.65
$E_c$ [cN/tex]	0.14	0.14	0.14
$\eta_s$ [cN.S/tex]	3.51	3.51	3.51
$\eta_{ve}$ [cN.S/tex]	6.14	6.14	6.14
$E_{ve}$ [cN/tex]	0.02	0.02	0.02
$C$ [cN/tex]	0.002	0.002	0.002
$n$	1.89	1.89	1.89
$S$ [cN/tex]	9.18	9.18	9.18
$\eta_{vp}$ [cN.S/tex]	0.82	0.82	0.82
$E_{vp}$ [cN/tex]	0.03	0.03	0.03
$\epsilon_p$ (mm)	41.78	40.34	43.68
$R^2$	0.99	0.98	0.97

Table 6: Rheological parameters of the proposed model for various extension rates.

suggested to describe the viscoelastoplastic behaviour of the elastic core spun yarn is validated.

The simulation results of the experimental curves concerning the tensile test for different yarns and various Dorlastan® drafts are presented in figure 10.

Figure 10 shows that, for various Dorlastan® drafts, the rheological

model adjust well the experimental curves of the tensile test of the yarn 100/156 with slight errors.

The same results are established for the elastic core spun yarns 50/78, 33.33/78, 33.33/44 and 25/44.

Table 7 indicates the obtained model parameters and the determination coefficient  $R^2$  of the tensile test of the elastic core

Yarn	100/156								
	Dorlastan® draft								
Rheological parameters	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
$\sigma_0$ [cN/tex]	0.7	0.65	0.64	0.6	0.54	0.52	0.5	0.48	0.43
$E_c$ [cN/tex]	0.13	0.14	0.11	0.13	0.14	0.14	0.13	0.13	0.11
$\eta_s$ [cN.S/tex]	3.94	3.51	3.09	3.1	3.18	3.12	3	2.82	2.85
$\eta_{ve}$ [cN.S/tex]	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14
$E_{ve}$ [cN/tex]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$C$ [cN/tex]	0	0	0	0	0	0	0	0	0
$n$	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89
$\eta_{vp}$ [cN.S/tex]	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
$E_{vp}$ [cN/tex]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$R^2$	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Yarn	50/78								
	Dorlastan® draft								
Rheological parameters	3.9	3.47	3.12	2.84	2.6	2.4	2.23	2.08	1.95
$\sigma_0$ [cN/tex]	1.11	0.86	0.81	0.79	0.7	0.69	0.63	0.62	0.51
$E_c$ [cN/tex]	0.16	0.16	0.17	0.17	0.16	0.16	0.16	0.15	0.18
$\eta_s$ [cN.S/tex]	3.57	3.57	3.58	3.2	2.84	2.94	2.82	2.67	2.45
$\eta_{ve}$ [cN.S/tex]	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14
$E_{ve}$ [cN/tex]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$C$ [cN/tex]	0	0	0	0	0	0	0	0	0
$n$	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89
$\eta_{vp}$ [cN.S/tex]	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
$E_{vp}$ [cN/tex]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$R^2$	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Yarn	33.33/44								
	Dorlastan® draft				Dorlastan® draft				
Rheological parameters	3.3	2.93	2.64	2.4	3.9	3.6	3.34	3.12	2.93
$\sigma_0$ [cN/tex]	1.15	1.09	1.01	0.97	0.92	0.85	0.79	0.71	0.65
$E_c$ [cN/tex]	0.19	0.2	0.17	0.19	0.19	0.17	0.17	0.16	0.16
$\eta_s$ [cN.S/tex]	3.54	3.48	3.19	2.54	3.33	3.21	3.25	2.65	2.66
$\eta_{ve}$ [cN.S/tex]	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14
$E_{ve}$ [cN/tex]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$C$ [cN/tex]	0	0	0	0	0	0	0	0	0
$n$	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89
$\eta_{vp}$ [cN.S/tex]	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
$E_{vp}$ [cN/tex]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$R^2$	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Yarn	25/44								
	Dorlastan® draft								
Rheological parameters	4.4	3.91	3.52	3.2	2.93	2.71	2.51	2.35	2.2
$\sigma_0$ [cN/tex]	1.69	1.39	1.34	1.11	1.01	0.93	0.87	0.76	0.79
$E_c$ [cN/tex]	0.17	0.18	0.19	0.19	0.16	0.17	0.2	0.17	0.17
$\eta_s$ [cN.S/tex]	3.48	3.53	3.23	3.29	2.92	2.77	2.5	2.74	2.54
$\eta_{ve}$ [cN.S/tex]	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14	6.14
$E_{ve}$ [cN/tex]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
$C$ [cN/tex]	0	0	0	0	0	0	0	0	0
$n$	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89	1.89
$\eta_{vp}$ [cN.S/tex]	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
$E_{vp}$ [cN/tex]	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
$R^2$	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99

**Table 7:** The rheological parameters and the determination coefficient for the tensile test of different elastic core spun yarns.



spun yarns 100/156, 50/78, 33.33/78, 33.33/44 and 25/44 for various Dorlastan® drafts.

Table 7 shows that the majority of rheological parameters remain constant for various Dorlastan® drafts except for the parameters  $E_c$  and  $\eta_s$  describing the mechanical behaviour of the elastic core spun yarn in the second zone of the tensile curve. These two parameters present also a variation according to the Dorlastan® draft, yarn count and Dorlastan® count.

In order to determine the impact of the experimental parameters as Dorlastan® draft, yarn count and Dorlastan® count on the two rheological parameters  $E_c$  and  $\eta_s$ , a multivariate linear regression modelling is used.

### Multivariate linear regression modelling of the rheological parameters $E_c$ and $\eta_s$

In order to study the normality of the variables, the test of Anderson Darling is used, as a statistical method, to check if the experimental tests follow or not a normal law.

Figure 11 presents the results of Anderson Darling tests of the rheological parameters  $E_c$  and  $\eta_s$ .

Figure 11 shows that all the experimental points fall according to the line plotted in the confidence intervals. Thus, the rheological coefficients  $E_c$  and  $\eta_s$  seem to follow a normal distribution.

Statistically, the probability value of Anderson Darling (AD) “P” for both parameters  $E_c$  and  $\eta_s$  are equal to 0.057 and 0.347 respectively, are higher than  $\alpha$  value equal to 0.05. Thus, the normal distribution seems to adapt the experimental data of those parameters.

The statistical models and analysis of the rheological parameters  $E_c$  and  $\eta_s$  are shown in table 8.

On table 8, we distinguish that the linear regressions of those models are highly significant since their P-value (null) lower than  $\alpha$ -value equal to 0.05 and the Fisher coefficient values F are very significant.

Thus the obtained equations explain a significant part of the out coming variations.

We can also know the impact of experimental parameters on the rheological parameters  $E_c$  and  $\eta_s$ .

We used the statistical analyses to determine the significance thresholds (P) of the experimental parameters and also to identify the degree of influence of each parameter that are shown in table 9.

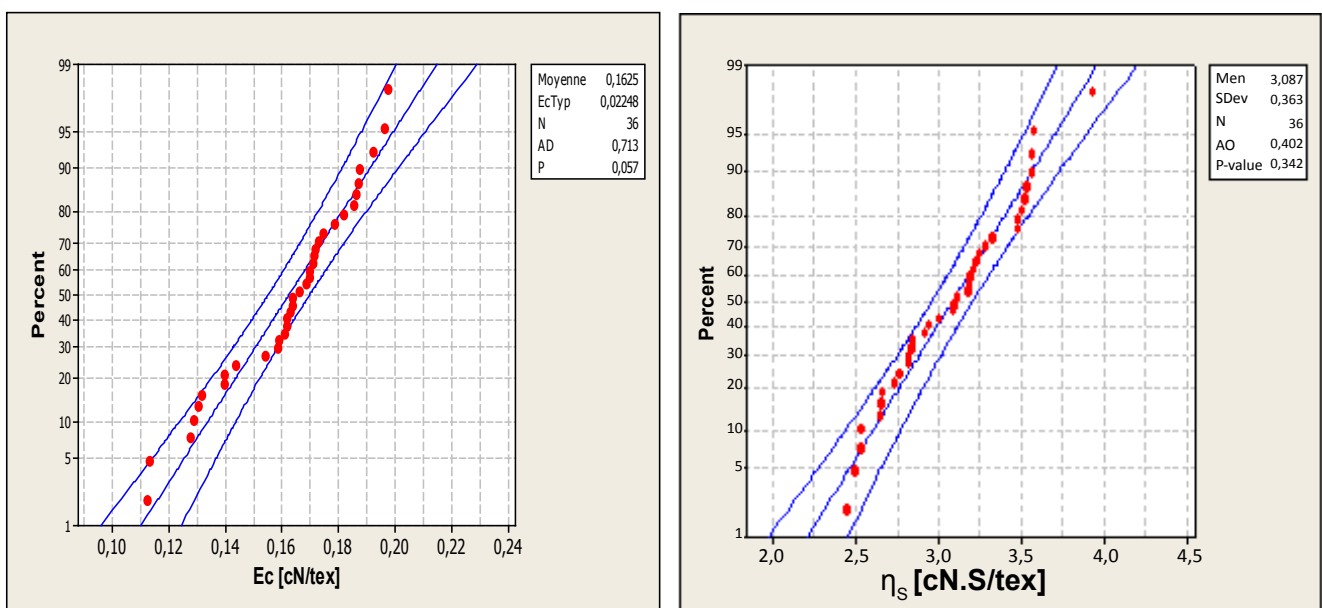
Table 9 shows that the experimental parameters do not affect the elasticity modulus  $E_c$ . Since, P-values are higher than the  $\alpha$ -value equal to 0.05. Therefore, according to the multivariate linear regression model established in table 8, the rheological parameter  $E_c$  is constant and equal to  $0.199 \approx 0.2$ . However, for the rheological parameter  $\eta_s$ , table 8 shows that the P-values (equal to 0.000) of the experimental parameters are lower than the  $\alpha$ -value. Thus, the yarn count, the Dorlastan® count and the Dorlastan® draft influence the viscosity modulus  $\eta_s$  describing the behaviour of the wrapping fibers in the second zone of the tensile curve.

As a result, the answer of the proposed model to the tensile test becomes:

$$\begin{aligned} \sigma(\varepsilon) = & 0.2 \times \varepsilon + (1.36 + 0.0242 \times Y_C - 0.0134 \times D_C) \times \varepsilon_0^0 \\ & + 6.14 \times \varepsilon_0^0 \times (1 - \exp(-0.003 \times (\frac{\varepsilon}{\varepsilon_0}))) \\ & + 0.002 \times \varepsilon^{1.89} + S + 0.82 \times \varepsilon_0^0 \times (1 - \exp(-0.036 \times (\frac{\varepsilon - \varepsilon_P}{\varepsilon_0}))) \end{aligned} \quad (2)$$

In order to make sure that the multivariate linear regression equation obtained for the rheological parameter  $\eta_s$  is a fitting approximation of the rheological model, the rheological experimental values were compared to those calculated by the statistical model (figure 12).

Figure 12 shows “a good” linear correlation between the rheological



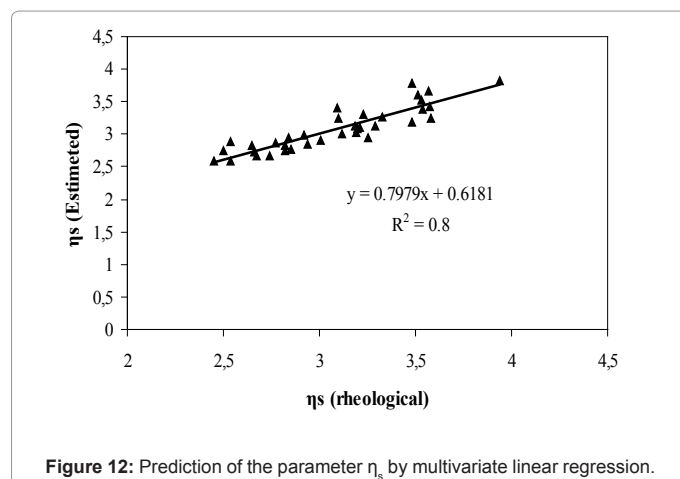
**Figure 11:** Anderson Darling test for the parameters  $E_c$  and  $\eta_s$ .

Response	Regressors	Model and statistical analysis
$E_c$	$X_1$ : yarn count (tex) $X_2$ : Dorlastan® count (dtex) $X_3$ : Dorlastan® draft	$Y=0.199-0.000090 X_1-0.000396 X_2+0.00067 X_3$ $R^2=80\%$ Fisher coefficient, $F=42.53$ Threshold of significance, $P=0.00$
$\eta_s$	$X_1$ : yarn count (tex) $X_2$ : Dorlastan® count (dtex) $X_3$ : Dorlastan® draft	$Y=1.36+0.0242 X_1-0.0134 X_2+0.549 X_3$ $R^2=80\%$ Fisher coefficient, $F=42.34$ Threshold of significance, $P=0.00$

**Table 8:** Statistical model and analysis of the parameters  $E_c$  and  $\eta_s$ .

Rheological parameters	Experimental parameters	significance Thresholds P
$E_c$	Yarn count	0.769
	Dorlastan® count	0.057
	Dorlastan® draft	0.823
$\eta_s$	Yarn count	0.000
	Dorlastan® count	0.000
	Dorlastan® draft	0.000

**Table 9:** Significance thresholds of the experimental parameters.



**Figure 12:** Prediction of the parameter  $\eta_s$  by multivariate linear regression.

parameter model and the parameter calculated starting from the linear regression equation, with an acceptable correlation coefficient  $R^2$  value equal to 0.8.

Thus, the statistical model obtained by multivariate linear regression for the rheological parameter  $\eta_s$  is valid.

## Conclusion

The study of the mechanical behaviour of the elastic core spun yarn in the tensile test, relaxation test and during cyclic test shows that the elastic core spun yarn presents a viscoelastoplastic solid behaviour with a nonlinear viscoelasticity. Hence, the model of the mechanical behaviour of the elastic core spun yarn is proposed. This model takes into account the behaviour of the yarn in the four zones of the tensile curve. The rheological model was validated for all the yarns for various Dorlastan® drafts. Indeed, this model adjusted well the experimental curves of the tensile test with a high determination coefficient  $R^2$ .

The identification of the model parameters shows that only the two rheological parameters  $E_c$  and  $\eta_s$  present a variation according

to the yarn count, Dorlastan® count and Dorlastan® draft. Thus, the statistical models of the two parameters by using the multivariate linear regression were done. The results of the multivariate linear regression modeling show that the parameter  $E_c$  remains constant and equal to 0.2. But, the parameter  $\eta_s$  depends on the experimental parameters.

## References

- Liu T, Choi KF, Li Y (2007) Mechanical Modeling of Singles Yarn. Text Res J 77: 123-130.
- Ghosh A, Ishtiaque SM, Rengasamy RS (2005) Stress-strain characteristics of different spun yarns as a function of strain rate and gauge length. J Text I 96: 99-104.
- Ussman MH, Manich AM, Gacen J, Maillo J (1999) Viscoelastic behaviour and microstructural modifications in acrylic fibres and yarns as a function of textile manufacturing processing conditions. J Text I 90: 526-540.
- Vangheluwe L (1992) Influence of Strain Rate and Yarn Number on Tensile Test Results. Text Res J 62: 586-589.
- Samah M, Neji L, Faouzi S (2007) Viscoelastic Behavior of Starch Sized Warps. Journal of Applied Science 7: 2376-2379.
- Sami BA, Naima H (2009) Prediction of the Mechanical Behavior of Open-End and Ring SPUN Yarns. Journal of Applied Sciences 9: 1466-1473.
- Yang HW, Kim HJ, Zhu CY, Huh Y (2009) Comparisons of Core—Sheath Structuring Effects on the Tensile Properties of High-Tenacity Ring Core-Spun Yarns. Text Res J 79: 453-460.
- Helali H, Babay AD, Msahli S (2012) Effect of elastane draft on the rheological modelling of elastane core spun yarn. J Text I 103: 451-457.
- Dorlastan in circular knitting. Asahi Kasei Spandex Europe GmbH, Dormagen, Germany.
- Rupp J, Bohringer A (1999) Yarns and Fabric Containing Elastane. International Textile Bulletin 1: 10-30.
- Standard reference atmosphere and natural atmosphere for conditioning and testing textiles. AFNOR.
- Lemaitre J, Chaboche JL (1994) Mechanics of Solid Materials. Cambridge University Press, UK.
- Ramier J, Jury MM (2004) Mechanical behavior of filled elastomers, Influence of load-polymer adhesion, Influence of morphology.
- Piezel B, Laiarinandrasana L, Renard J, Thionnet A (2009) Analyse expérimentale d'un composite textile en vue d'une modélisation multiéchelle. Comptes Rendus des JNC 16-Toulouse France.
- Helali H, Dhoubi AB, Msahli S, Cheikhrouhou M (2012) Influence of Dorlastan® draft and yarn count on the elastic recovery of the Dorlastan® core spun yarns following cyclic test. J Text I 103: 378-384.