Journal of Applied Sciences

ISSN 1812-5654

Journal of Applied Sciences 9 (8): 1466-1473, 2009
ISSN 1812-5654

Prediction of the Mechanical Behavior of Open-End and Ring SPUN Yarns

[1]B.A. Sami and [2]H. Naïma
[1]Laboratory of Study of The Thermal and Energy Systems, National School Engineers of Monastir, Ibn El-Jazzar, Monastir, 5019, Tunisia
[2]Textile Research Unit of Higher Institute of Technologie Study, ISET of Ksar Hellal, Monastir, Tunisia

Abstract: The objective of this study is to predict the mechanical behaviour of yarns under various levels of strain, by using only their technical parameters. The study of the yarn response to tensile test and relaxation test at different strain levels has permitted us to propose an analytical model predicting the entire stress-strain response of yarn. We have used the rheological approach to propose this analytical model. This model permitted to describe the viscoelastic behaviour of ring and open-end spun yarns during traction and relaxation. In order to characterize the coefficients of the proposed model, traction and relaxation tests were performed for 44 yarns. The neuronal approach is used to study the correlation between the mechanical coefficients of the analytical model and the technical parameters of the spinning mill. This allowed us to predict the yarns mechanical behaviour.

Key words: Modeling, yarns mechanical behavior, viscoelastic, prediction, neuronal network

INTRODUCTION

The mechanical properties of textile yarns play a phenomenal role in the process ability and the quality of the end products. For this reason, several works have been carried out to study these properties and the mechanical behaviour of yarns. The early research studies of Gegauff (1907), Gurney (1925) and Peirce (1926) aimed to establish a theoretical relationships between fibre properties, textile structural factors and material behaviour. These studies led to the foundation of modern textile mechanics. Since 1940, this field has been developed extensively by many researchers including Sullivan (1942), Platt (1950), Gregory (1953a, b), Hearle (1958), Hearle *et al.* (1961), Treloar and Riding (1963), Treloar (1965a, b), Postle *et al.* (1988), Carnaby and Grosberg (1976) and Pan (1992, 1993a, b). More recently, Shao *et al.* (2005 a, b) proposed in their studies to predict the entire load-extension response of low-twist staple yarns, have taken into consideration fibre slippage, using the analytical method of the finite element. They have also used this model to study the response of such yarns when subjected to cyclic tensile loading.

In other studies, the researchers have shown that the yarns have viscoelastic behaviour. Among the most used mechanical models, to describe this behaviour, are those of Vangheluwe (1992, 1993) and Zurek and Aksam (1975). Ghosh *et al.* (2005) have used a modified form of Vangheluwe model to compare the behaviour of different yarns (ring, rotor, air-jet and open-end friction yarns) at different levels of strain rate and gauge length. Albert *et al.* (1999) modified the models of Vangluwe (1992, 1993) and Zurek (1975) to simulate the polypropylene fibre behaviour for different mass dope dyeing. These two models are also used by Mohamed *et al.* (1999) to study the behaviour of acrylic yarns and fibres extracted from various steps of textile processing.

In order to predict the mechanical behaviour of yarns, we introduced some modifications on a viscoelastic rheological model of linear solid. To facilitate the identification of the coefficients of the proposed model, a tensile test and a relaxation test for different strain levels were carried out on ring and open-end yarns. Thereafter, a multilayer perception neuronal structure (Ladjadj, 2003) was trained with retro-propagation algorithm and permitted to correlate technical parameters of yarns and the mechanical coefficients of the proposed model.

MATERIALS AND METHODS

In order to study the yarns mechanical behaviour, simple tensile tests were performed according to the French norm (Norme, 1971) (NF-G 07-003). The test consists of applying a traction effort at a constant speed 100 mm min^{-1} to a yarn sample of 500 mm length and then relaxation tests at different strain levels were carried out for 44 yarns ring and open-end. These yarns were spun from cotton fibres, PET fibres and mixture of these fibres x% cotton and 100-x% PET. Table 1 shows the different tested yarns and their technical parameters. These spun yarns are designated by the code «Sm [Nm/type-α-Comp]».

Corresponding Author: Halleb Naima, Rue Amor Bayoudh, 5080 Téboulba, Monastir, Tunisia Tel: +216 97640557

Table 1 : Technical characteristics of tested samples

No. Code yarn	Spinning mill	Nm	α torsion ($Tr.g.m^{-2}$)	Composition (%)
1 RG[40/2-94-100%C]	Ring	40/2	94	100% cotton
2 RG[40/2-133-100%C]	Ring	40/2	133	100% cotton
3 OE[40/1-161-100%C]	Open-end	40/1	161	100% cotton
4 RG[50/1-110-100%C]	Ring	50/1	110	100% cotton
5 RG[50/1-110-100%C]	Ring	50/1	110	100% cotton
6 RG[50/1-130-100%C]	Ring	50/1	130	100% cotton
7 OE[12/1-158-100%C]	Open-end	12/1	158	100% cotton
8 OE[40/2-178-100%C]	Open-end	40/2	178	100% cotton
9 OE[40/2-94-100%C]	Open-end	40/2	94	100% cotton
10 OE[34/1-160-100%C]	Open-end	34/1	160	100% cotton
11 OE[28/1-159-100%C]	Open-end	28/1	159	100% cotton
12 OE[12.5/1-138-100%C]	Open-end	12.5/1	138	100% cotton
13 OE[34/1-111-100%P]	Open-end	34/1	111	100%PET
14 OE[40/1-161-100%C]	Open-end	40/1	161	100% cotton
15 OE[24/1-116-33%C67%P]	Open-end	24/1	116	33% cotton67%PET
16 RG[44/1-116-33%C67%P]	Ring	44/1	116	33% cotton67%PET
17 RG[26/1-116-33%C67%P]	Ring	26/1	116	33% cotton67%PET
18 OE[17/1-114-33%C67%P]	Open-end	17/1	114	33% cotton67%PET
19 OE[27/1-113-33%C67%P]	Open-end	27/1	113	33% cotton67%PET
20 RG[14/1-187-100%C]	Ring	14/1	187	100% cotton
21 RG[40/1-187-100%C]	Ring	40/1	187	100% cotton
22 RG[10/1-142-100%C]	Ring	10/1	142	100% cotton
23 RG[10/1-158-100%C]	Ring	10/1	158	100% cotton
24 RG[10/1-174-100%C]	Ring	10/1	174	100% cotton
25 RG[12.5/1-127-100%C]	Ring	12.5/1	127	100% cotton
26 RG[12.5/1-141-100%C]	Ring	12.5/1	141	100% cotton
27 RG[12.5/1-155-100%C]	Ring	12.5/1	155	100% cotton
28 RG[15/1-116-100%C]	Ring	15/1	116	100% cotton
29 RG[15/1-129-100%C]	Ring	15/1	129	100% cotton
30 RG[15/1-142-100%C]	Ring	15/1	142	100% cotton
31 RG[17/1-109-100%C]	Ring	17/1	109	100% cotton
32 RG[17/1-121-100%C]	Ring	17/1	121	100% cotton
33 RG[17/1-133-100%C]	Ring	17/1	133	100% cotton
34 RG[17/1-133-100%C]	Ring	20/1	100	100% cotton
35 RG[17/1-133-100%C]	Ring	20/1	112	100% cotton
36 RG[17/1-133-100%C]	Ring	20/1	123	100% cotton
37 OE[13/1-166-100%C]	Open-end	13/1	166	100% cotton
38 OE[17/1-146-100%C]	Open-end	17/1	146	100% cotton
39 OE[20/1-134-100%C]	Open-end	20/1	134	100% cotton
40 OE[28/1-113-100%C]	Open-end	28/1	113	100% cotton
41 OE[34/1-103-100%C]	Open-end	34/1	103	100% cotton
42 OE[40/1-95-100%C]	Open-end	40/1	95	100% cotton
43 RG[44/1-110-35%C65%P]	Ring	44/1	110	35% cotton65%PET
44 RG[60/1-110-35%C65%P]	Ring	60/1	110	35% cotton65%PET

This code gives access to the five technical parameters of yarn, taken into account in this study: Sm is the spinning mill of yarn (ring RG and open-end OE). Nm is the metric number of the spun yarn (between 10 and 60) and the type of yarn (simple or twisted). Comp is the yarn composition fibres (C: 100% cotton, P: 100% PET, x C: blend x % cotton and 100-x%PET). α is the torsion coefficient (between 94 and 187).

We, respectively define the experimental stress (σ (N mg^{-1})) and strain (ε) as follows:

$$\sigma = \frac{\text{Force}}{\text{Nm}} \quad (1)$$

$$\varepsilon = \frac{\Delta L}{L} \quad (2)$$

RESULTS AND DISCUSSION

For the majority of the studied yarns, the curve (Fig. 1a-d) of the stress (σ) variation according to the strain (ε) represents a nonlinear form.

The represented curves were selected in manner to show the variation of the form of traction diagram according to Nm (Fig. 1a-b), to composition (Fig. 1c), to torsion coefficient α (Fig. 1d) and to spinning mill (Fig. 1a, b).

The figures show the influence of variation of the parameters quoted previously. But we noted that the traction curves have the same forms in all the studied cases, except the case when the percentage of PET is very high the shape of the curve becomes a little different.

Relaxation tests were carried out at different strain levels (ε_0 = 0.0184, 0.024, 0.032, 0.04, 0.048, 0.056, 0.064, 0.07, 0.767, for yarn No.1). Three examples of obtained curves are shown in Fig. 2. The shape of the relaxation curves (Fig. 2) highlights the viscoelastic behaviour of the fabric. This behaviour will be modelled by a Maxwell element (Lemaître and Chaboche, 1988) and an elastic element placed in parallel.

During the relaxation test, we noticed that the yarn needs a long time to be stabilized. Therefore, we limited the relaxation period to a value where the slope of the curve becomes weak, in order to simplify the experimental work.

Theoretical model: The experimental relaxation curves (Fig. 2) of the studied yarns, show that the shape of these curves can be described by the following Eq. 3:

$$\sigma(\varepsilon_0, t) = \left[\sigma(\varepsilon_0, 0) - \sigma(\varepsilon_0, \infty)\right] e^{-\frac{t}{\tau}} + \sigma(\varepsilon_0, \infty) \quad (3)$$

This equation corresponds to a rheological model, containing a Maxwell element assembled in parallel with an elastic element that depends of ε.

We defined the relaxation stress:

$$\sigma_r(\varepsilon_0) = \sigma(\varepsilon_0, 0) - \sigma(\varepsilon_0, \infty) \quad (4)$$

The Fig. 3a and b show respectively the curves of variation of the stress $\sigma(\varepsilon_0, \infty)$ and $\sigma(\varepsilon_0)$ according to the initial relaxation strain for two yarns open-end and ring chosen like examples.

We have noted that the curve (Fig. 3a) of variation of the stress $\sigma(\varepsilon_0, \infty)$ according to the initial relaxation strain (ε_0) represents a nonlinear form, which allowed us to conclude that the elastic element is a nonlinear spring, having a behaviour described by:

$$\sigma_2(\varepsilon) = A\varepsilon^n \quad (5)$$

where, σ_2 and ε are the stress (N mg^{-1}) and strain of the nonlinear spring, A is spring coefficient (N mg^{-1}) and n>0.

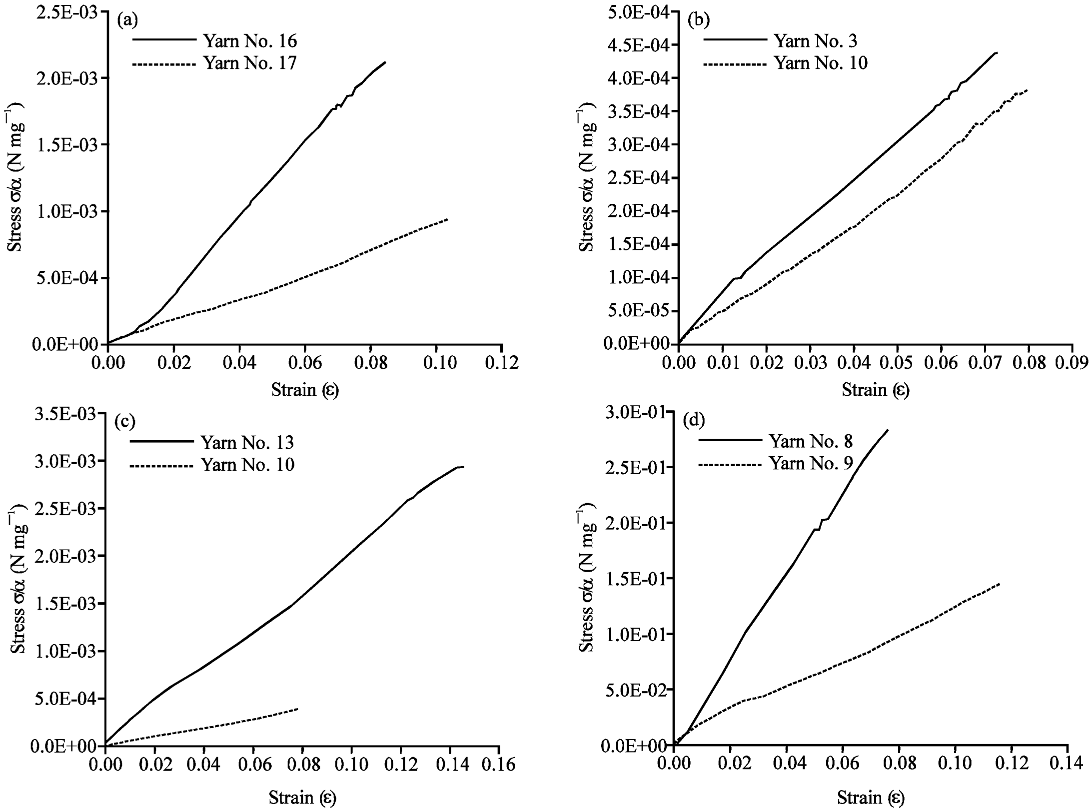

Fig. 1: (a) Traction curve of ring yarns (Nm 44/1 and Nm 26/1), (b) Traction curve of open-end yarns (Nm 40/1 and Nm 34/1), (c) Traction curve of open-end yarns (cotton and PET) and (d) Traction curve of open-end yarns (α =178 and 94)

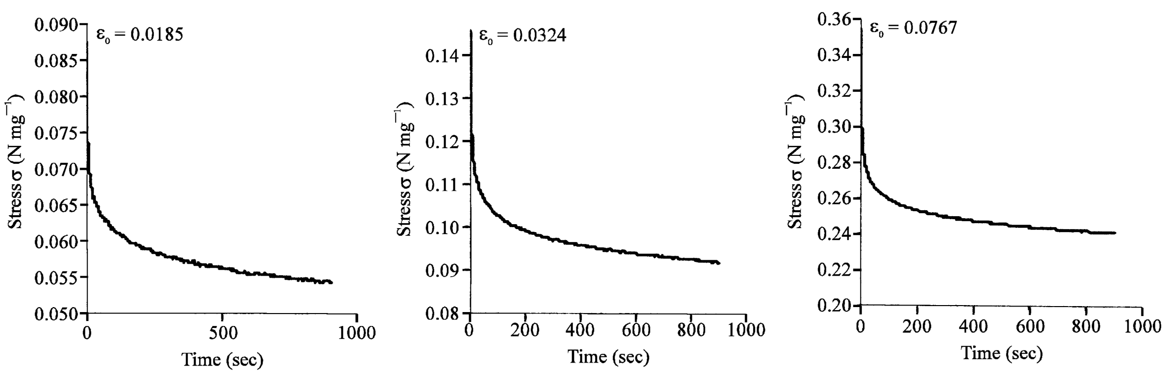

Fig. 2: Relaxation curve of yarn No. 1 for 3 different strain levels

We have noted that the curve (Fig. 3b) of variation of the stress difference $\sigma_r(\varepsilon_0)$ according to the initial relaxation strain (ε_0) represents a linear form. This proves that, the spring of Maxwell element is linear.

Figure 4 shows the viscoelastic model, which we used, in the beginning, to simulate the behaviour of yarn during traction and relaxation. In this model a nonlinear spring is placed in parallel with a Maxwell element.

However, the behaviour of this model during traction and relaxation is mathematically described, respectively by Eq. 6 and 7:

$$\sigma(\varepsilon) = A\varepsilon^{n} + N\dot{\varepsilon}\left(1 - e^{\frac{-\varepsilon}{\tau\dot{\varepsilon}}}\right) \tag{6}$$

$$\sigma(\varepsilon_0, t) = E\varepsilon_0 e^{-\frac{t}{\tau}} + \sigma(\varepsilon_0, \infty) \tag{7}$$

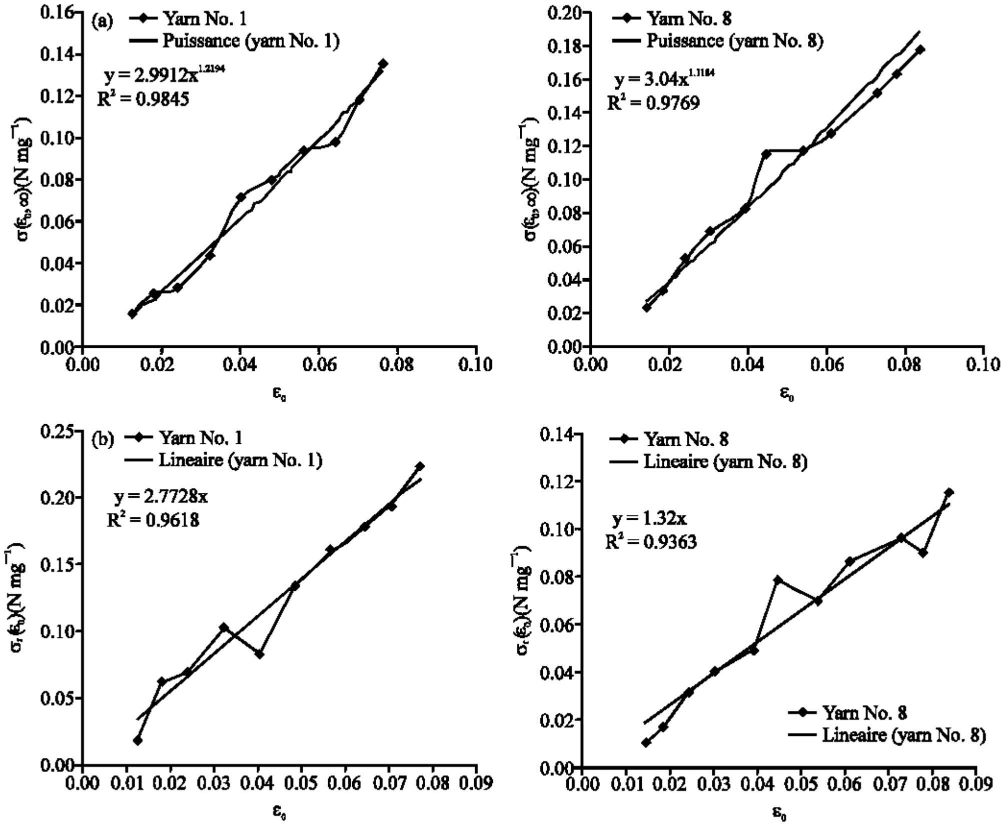

Fig. 3: (a) Variation of the stress $\sigma(\varepsilon_0, \infty)$ and (b) Variation of $\sigma(\varepsilon_0)$

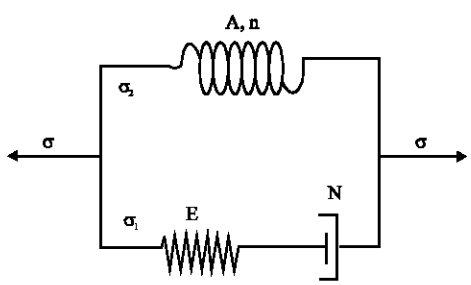

Fig. 4: Viscoelastic model of yarn

where, $\sigma_r(\varepsilon_0, \infty)$ is a nonlinear function of ε_0 ($\sigma(\varepsilon_0, \infty) = A\varepsilon_0^n$), E is the spring modulus (N mg^{-1}), N is the viscosity (Ns mg^{-1}) of the dashpot in the Maxwell element and $\tau = N/E$ is its relaxation time.

In order to obtain a best fit of the experimental tension and relaxation curves, an exponent (p>0) was introduced to the exponential function. Thus, the behaviour of yarn in tension and relaxation will be expressed respectively as follows:

$$\sigma(\varepsilon) = A\varepsilon^n + N\dot{\varepsilon}\left(1 - e^{-\frac{1}{\tau}\left(\frac{\varepsilon}{\dot{\varepsilon}}\right)^p}\right) \tag{8}$$

$$\sigma(\varepsilon_0, t) = E\varepsilon_0 e^{-\frac{t^p}{\tau}} + \sigma(\varepsilon_0, \infty) \tag{9}$$

We have five values to be calculated. The coefficients E, p and τ are identified from the relaxation curves Eq. 9 for different levels of strain (Fig. 5a, b) using the least square method. N is deduced from the values of E and τ. The same method is used to identify the coefficients A and n of the nonlinear spring from the traction curve (Fig. 6a, b), by using Eq. 8. These coefficients are calculated for different spun yarns. Table 2 shows the 5 coefficients of the proposed model, σ_{max} and ε_{max} for the 44 spun yarns.

Prediction of the yarn mechanical behaviour: By neural network: In order to predict the mechanical behaviour of a spun yarn through the 5 coefficients of the proposed model, we applied the neuronal approach (Cyril Roussillon, 2005). This approach is inspired from the operational principle of biological neurones network, which consists in the summing of the entries coming from other neurons thanks to its dendrites, then the analysis of information and the result of the analysis will forward along the axon until the synaptic terminations.

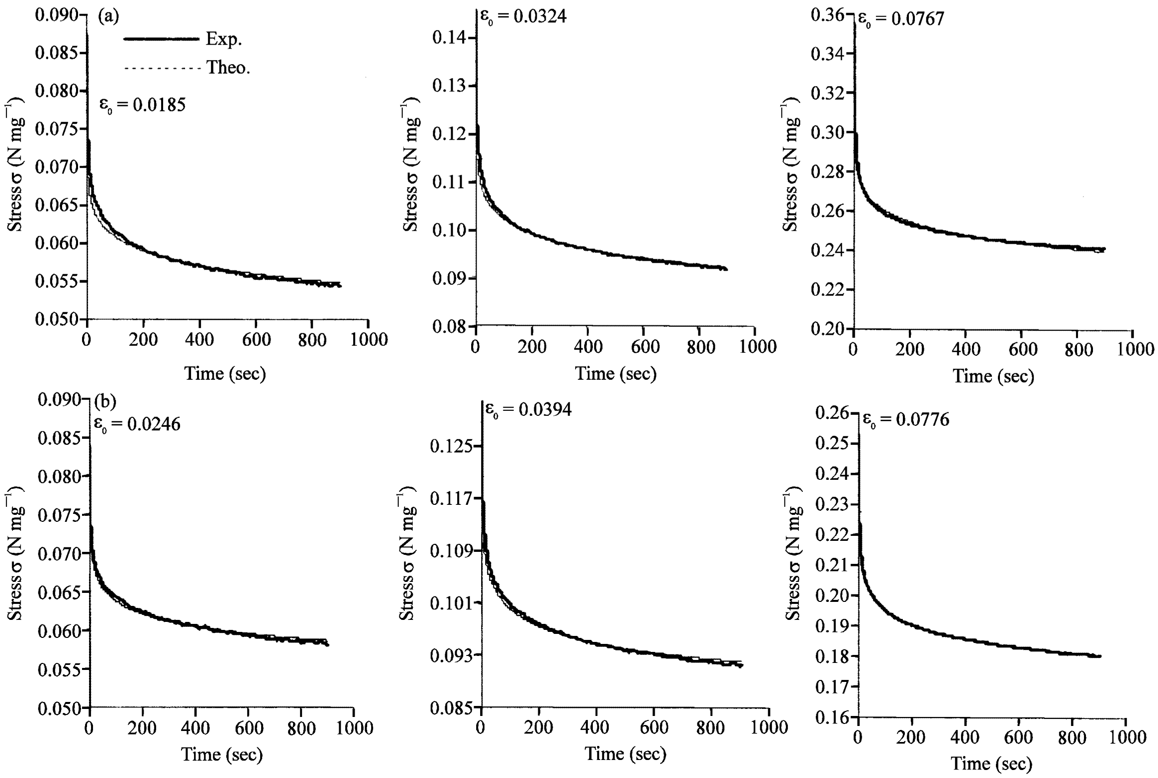

Fig. 5: (a) Experimental and theoretical relaxation curve of yarn No. 1 for 3 strain levels and (b) Experimental and theoretical relaxation curve of yarn No.8 for 3 strain levels

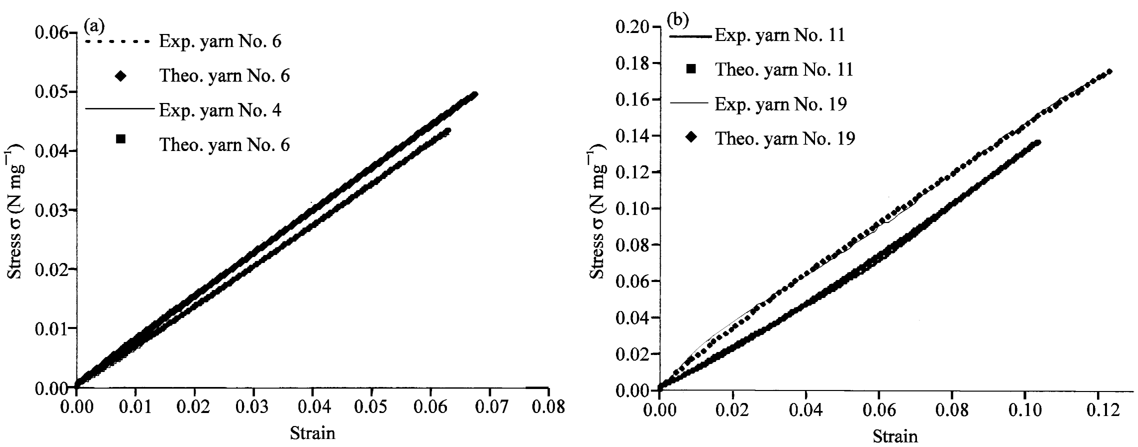

Fig. 6: (a, b) Experimental and theoretical traction curve

We developed a neural network simulating software based on the back-propagation algorithm, which provides the desired coefficients value of the proposed model starting from the technical parameters of spun yarns.

The yarn mechanical behaviour during traction depends on different parameters:

- Fibers resistance to traction which is generated by the nature of the fibers
- Number of fibers by section which is linked to the Nm,
- Lateral pressure between the fibers which is generated by the coefficient of torsion α and the type of yarn and the spinning mill

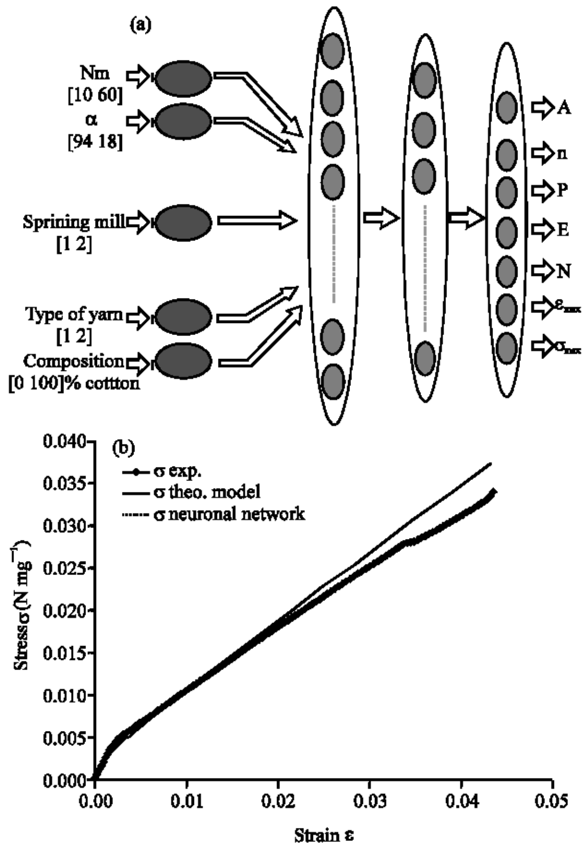

Fig. 7: (a) The neuronal model and (b) Traction curve after prediction

Hence, the yarn mechanical behaviour during traction depends essentially of; Nm, nature of the fibers, spinning mill, coefficient of torsion α and the type of yarn. For this reason, we have took into account only these 5 parameters to predict the mechanical behaviour of yarns.

We used a neuronal structure of a multi-layer perceptron type (Ladjadj, 2003). This neuronal structure (Fig. 7a) comprises an entry layer of five entries (spinning mill, metric number Nm, torsion α, composition fibers, type of yarn), two hidden layers the first hidden layer presents 4 neurons and the second presents 3 neurons and an exit layer which presents the 5 coefficients of the proposed model, σ_{max} and ε_{max}. Knowing that, each of this coefficient is calculated separately. The transfer function applied to the two hidden layers is Tansig and for the exit layer is Purilin.

This neuronal model is trained with a database of 40 samples chosen arbitrarily. The last six lines of Table 2 present the error of apprenticing E_a of 40 yarns. After that, the values of each coefficient are obtained by testing the neurones network on the 4 yarns and the error of test E_t in question.

Table 2: The identified coefficients of the model and the neuronal approach for 4 yarns

No. Code yarn	E (N mg^{-1})	A (N mg^{-1})	N (Ns mg^{-1})	n	p	σ_{max} (N mg^{-1})	ε_{max}
1 RG[40/2-94-100%C]	2.720	9.04	7.92	1.24	0.13	0.353	0.079
2 RG[40/2-133-100%C]	0.543	1.40	7.81	1.325	0.231	0.308	0.089
3 OE[40/1-161-100%C]	0.547	1.425	0.874	0.979	0.236	0.069	0.073
4 RG[50/1-110-100%C]	0.238	0.56	0.801	1.063	0.259	0.043	0.063
5 RG[50/1-110-100%C]	0.650	3.901	0.718	1.009	0.14	0.041	0.057
6 RG[50/1-130-100%C]	0.239	0.537	0.709	0.992	0.208	0.050	0.067
7 OE[12/1-158-100%C]	3.371	10.006	8.666	1.141	0.144	0.754	0.116
8 OE[40/2-178-100%C]	1.201	3.02	3.866	1.013	0.21	0.289	0.076
9 OE[40/2-94-100%C]	1.010	3.10	6.387	1.286	0.276	0.245	0.084
10 OE[34/1-160-100%C]	0.644	3.00	1.369	1.133	0.171	0.108	0.104
11 OE[28/1-159-100%C]	0.563	2.00	1.847	1.156	0.215	0.137	0.103
12 OE[12.5/1-138-100%C]	2.239	6.68	11.587	1.209	0.238	0.793	0.109
13 OE[34/1-111-100%P]	0.625	1.90	0.978	0.907	0.304	0.142	0.116
14 OE[40/1-161-100%C]	0.255	0.69	1.037	1.127	0.281	0.061	0.079
15 OE[24/1-116-33%C67%P]	0.628	1.69	2.414	1.026	0.289	0.301	0.129
16 RG[44/1-116-33%C67%P]	0.256	1.99	0.785	0.965	0.437	0.089	0.101
17 RG[26/1-116-33%C67%P]	0.556	2.555	2.402	1.034	0.35	0.328	0.145
18 OE[17/1-114-33%C67%P]	0.912	8.550	3.169	0.859	0.446	0.483	0.109
19 OE[27/1-113-33%C67%P]	0.440	3.517	1.197	0.926	0.426	0.176	0.122
20 RG[14/1-187-100%C]	4.306	14.166	1.554	0.959	0.416	0.481	0.269
21 RG[40/1-187-100%C]	1.147	3.483	1.492	1.051	0.337	0.087	0.063
22 RG[10/1-142-100%C]	6.248	10.767	30.453	1.353	0.371	1.470	0.105
23RG[10/1-158-100%C]	6.274	12.520	33.527	1.434	0.249	1.747	0.126
24 RG[10/1-174-100%C]	9.432	17.307	33.127	1.535	0.261	1.577	0.135
25 RG[12.5/1-127-100%C]	12.163	25.068	24.601	1.509	0.298	1.040	0.118
26 RG[12.5/1-141-100%C]	7.534	12.028	18.556	1.282	0.32	1.023	0.102
27 RG[12.5/1-155-100%C]	4.454	7.686	18.669	1.314	0.264	0.857	0.0942
28 RG[15/1-116-100%C]	2.394	3.777	7.913	1.055	0.344	0.549	0.078
29 RG[15/1-129-100%C]	3.870	5.837	9.864	1.115	0.283	0.593	0.078
30 RG[15/1-142-100%C]	3.976	6.804	10.288	1.212	0.283	0.614	0.095
31 RG[17/1-109-100%C]	5.020	7.613	4.567	0.898	0.335	0.396	0.062
32 RG[17/1-121-100%C]	3.653	5.420	9.63	1.252	0.312	0.494	0.091
33 RG[17/1-133-100%C]	8.044	13.057	7.708	1.126	0.332	0.505	0.083
34 RG[17/1-133-100%C]	2.068	3.028	5.782	1.173	0.314	0.295	0.080
35 RG[17/1-133-100%C]	4.297	6.557	6.046	1.192	0.294	0.319	0.081
36 RG[17/1-133-100%C]	5.754	9.579	8.613	1.344	0.341	0.332	0.083
37 OE[13/1-166-100%C]	5.014	13.041	12.117	1.102	0.311	0.817	0.084
38 OE[17/1-146-100%C]	4.427	11.891	6.551	1.073	0.347	0.421	0.073
39 OE[20/1-134-100%C]	2.535	6.808	4.466	1.067	0.347	0.269	0.069
40 OE[28/1-113-100%C]	1.072	2.879	1.944	1.012	0.347	0.124	0.063
41 OE[34/1-103-100%C]	1.541	2.352	1.408	1.025	0.23	0.081	0.057
42 OE[40/1-95-100%C]	0.850	2.001	0.517	0.914	0.35	0.044	0.044
43 RG[44/1-110-35%C65%P]	0.330	1.106	0.21	0.607	0.487	0.078	0.172
44 RG[60/1-110-35%C65%P]	0.041	0.11	0.109	0.497	0.427	0.033	0.101
E_a (%)	0.250	7.321^{e-2}	0.380	0.510	0.720	5.525^{e-2}	0.120
Yarn No. 8 after prediction	1.163	2.206	1.093	1.168	0.216	0.087	0.054
Yarn No. 24 after prediction	5.251	21.083	13.392	1.209	0.336	0.205	1.266
Yarn No. 31 after prediction	4.356	8.537	7.75	1.221	0.323	0.083	0.484
Yarn No. 42 after prediction	0.8365	1.765	1.017	0.984	0.26	0.061	0.0552
E_t (%)	7.960	4.84	2.00	7.9	25.5	2.23	5.47

The error values obtained are acceptable although the database used to train the neuronal model is small. Figure 7b shows an example of traction curve obtained after prediction for the yarn No. 42. The proposed neuronal model allowed us to predict to an error close the totality of the yarn traction curve starting only 5 technical parameters, which already consists a great step compared to former work.

CONCLUSION

The study of the relaxation and traction curves allowed us to prove that the yarns have a viscoelastic behaviour. We modeled this behaviour with a modified form of a viscoelastic rheological model. This model contains a Maxwell element placed in parallel with a nonlinear spring. The modification that we introduced to the Maxwell element, in order to fit better the experimental curves, consists in adding an exponent to the exponential function.

The proposed model yields good results for all the studied yarns. It permitted to model the behaviour of these yarns during relaxation and traction. The coefficients of the proposed model can be identified from only one traction curve and two relaxation curve to different strain levels.

We developed a neuronal model which enabled us to predict with a meadows error the coefficients of the analytical model and consequently the mechanical behaviour of open-end and ring spun yarns starting only from their technical parameters. The technical parameters which we have took into account in this study were; spinning mill, metric number Nm, torsion α, fibers proportions, type of yarn.

The results obtained by neuronal networks can be ameliorated by improving the database used to train the neuronal model or by using another approach.

Finally we can conclude that, using the proposal's analytical model and of neuronal model, we could predict with a meadows error the mechanical behavior of studied yarns during traction and relaxation starting from five technical parameters.

This can help the manufacturers to predict the yarns behaviour under various levels of strain and their tenacity before producing. This permitted also, to reduce the number of samples and tests which will be carried out to determine the quality of yarns. As a result production of high quality yarns with less investment.

NOTATION

A = Coefficient of non-linear spring ($N\ mg^{-1}$)
E = Spring modulus ($N\ mg^{-1}$) in the Maxwell element
N = Viscosity ($N\ s\ mg^{-1}$) of the dashpot in the Maxwell element
L = Length of tested sample (mm)
ΔL = Elongation of tested sample (mm)
ε = Strain,
$\dot{\varepsilon}$ = Speed of strain ($m\ sec^{-1}$)
Σ = Stress ($N\ mg^{-1}$)

ACKNOWLEDGMENTS

We would like to express our sincere thanks to Dr. Adel M. Allimi for his particular help. Our acknowledgments go to Mr. Ramdhan Bouchrait the engineer from SITEX for his help to prepare the spun yarn samples.

REFERENCES

Albert, M.M., H.U. Mohamed and B. Alberto, 1999. Viscoelastic behabior of polypropylene fibers. Textile Res. J., 69: 325-330.

Carnaby, G.A. and P. Grosberg, 1976. The tensile behavior of staple fiber yarns at small extensions. J. Text. Inst., 67: 299-308.

Cyril Roussillon, 2005. Regression and predict of the temperature. Available at:: http://crtechnologies.free.fr/projets/tipe reseauxneuronaux.

Gegauff, C.M., 1907. Strength and elasticity of cotton threads. Bull. Soc. Inductr. Mulhouse, 177: 150-150.

Ghosh, A., S.M. Ishtiaque and R.S. Rengasang, 2005. Stress-strain characteristics of different spun yarns as a function of strain rate and gauge length. J. Text. Inst., 96: 99-104.

Gregory, J., 1953a. The strength of twisted yarn elements in relation to the properties of the constituent fibers. J. Text. Inst., 41: T499-T499.

Gregory, J., 1953b. The relation between strength measurements made on fiber, fiber bundles, yarns and cloths. J. Text. Inst., 41: T515-T515.

Gurney, H.P., 1925. The distribution of stresses in cotton products. J. Text. Inst., 16: T269-T269.

Hearle, J.W.S., 1958. The mechanics of twisted yarns: The influence of transverse forces on tensile behavior. J. Text. Inst., 49: T389-T389.

Hearle, J.W.S., H.M.A.E. El-Behery and V.M. Thakur, 1961. The mechanics of twisted yarns: Theoretical developments. J. Text. Inst., 52: T197-T197.

Lemaître, J. and J.L. Chaboche, 1988. Mécaniques Des Materiaux Solides, Publie Avec Le Concours Du Greco (Grandes Deformations Et Endommagement De Cnrs Et De L'onera). 2nd Edn., BORDAS, Paris.

Ladjadj, R., 2003. Site concerning the artificial intelligence in general and neuronal network. http://www.generation5.org.

Mohamed, H.U., M.M. Albert, J. Gacen and J. Maillo, 1999. Viscoelastic behaviour and microstructural modifications in Acrylic fibers and yarns as a function of textile manufacturing processing conditions. J. Text. Inst., 90: 526-540.

Norme, F., 1971. Textile. Tome I, Editee Par L'association Française De Normalisation (AFNOR). 1st Edn., La Defense, Paris.

Pan, N., 1992. Development of a constitutive theory for short fiber yarns: Mechanics of staple yarn without slippage effect. Text. Res. J., 62: 749-749.

Pan, N., 1993a. Development of a constitutive theory for short fiber yarns part II: Mechanics of staple yarn without slippage effect. Text. Res. J., 63: 504-504.

Pan, N., 1993b. Prediction of statistical strengths of twisted fiber structures. J. Mater. Sci., 28: 6107-6114.

Peirce, F.T., 1926. Tensile tests for cotton yarns; V. The weakest link theorems on the strength of long composite specimen. J. Text. Inst., 17: T355-T355.

Platt, M.M., 1950. Mechanics of elastic performance of textile materials, Part IV. Some aspects of stress analysis of textile structures-staple fiber yarns. Text. Res. J., 20: 519-519.

Postle, R., G.A. Carnaby and S.D.E. Jong, 1988. The mechanics of wool structure. Ellis Horwood Limited, England.

Shao, X., Y. Qiu and Y. Wang, 2005a. Theoretical modeling of the tensile behaviour of low-twist staple yarns: Part I- theoretical model. J. Text. Inst., 96: 61-68.

Shao, X., Y. Qiu and Y. WANG, 2005b. Theoretical modeling of the tensile behavior of low-twist staple yarns: Part II- theoretical and experimental results. J. Text. Inst., 96: 69-76.

Sullivan, R.R., 1942. A theoretical approach to the problem of yarn strength. J. Applied Phys., 13: 157-157.

Treloar, L.R.G. and G. Riding, 1963. A theory of stress-strain properties of continuous-filament yarns. J. Text. Inst., 54: T156-T156.

Treloar, L.R.G., 1965a. A migrating-filament theory of yarn properties. J. Text. Inst., 56: T359-T359.

Treloar, L.R.G., 1965b. The stress-strain properties of multiply cords, part I. Theory. J. Text. Inst., 56: T477-T477.

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

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

Zurek, W. and S. Aksan, 1975. A Rheological model of viscose rayon. J. Applied. Polym. Sci., 19: 3129-3137.