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Research Article

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Study of the Theoretical and Rheological Models for the Mechanical Behaviour of Cotton Core Spun Yarn with Elastane

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Abstract

This work is the development of tools and powerful models to characterize the dynamometric properties of cotton core spun yarn with elastane starting from the fibre properties composing this yarns (by taking account of the experimental and theoretical results) to find laws of mechanical behaviour starting from different rheological models and from the mechanical requests such as traction and relaxation. These tools will make it possible to analyse and to optimize the composition and the characteristics of produced yarns.

Keywords: Dynamometric properties, core spun yarn with elastane, mechanical behaviour, rheological models

Introduction

This part consists to analyse and identify some mechanical models of behaviour for textile fibres and yarns and to compare their respective behaviour laws with the answers of cotton core spun yarn with elastane to the tensile tests. This part consists in suitable studying of the existing rheological models of behaviour like that of Vangheluwe, Zurek and Manich, by finding their laws of behaviour.

Material and Methods

To study the mechanical behaviour of spun cotton fibres that we built, we performed tensile tests carried out using a Lloyd dynamometer LR5K according to NFG 07-003 norm.

From the software of the dynamometer, it was possible to extract the force-elongation curves for each test. The tensile tests give us an idea about the models of correlation between the properties of yarns and fibres to make a comparison and a validation of mathematical tools in order to know the most influential properties on tenacity, elongation and other characteristics of the yarn.

So, we used a dynamometer for the yarn tensile tests and the software Matlab to study rheological models and behaviour of cotton core spun yarn with elastane.

Cotton crop study data of 1997 and 1998 published by the International Textile Center, USA, were used in our investigation. In this experimental study, we used some different input parameters for cotton, elastane and dynamometric properties of core spun yarns [1].

The summary statistics for fibre and elastane properties and core spun yarn count and twist are shown in table 1 and 2.

The outputs of each prediction model were breaking tenacity and breaking elongation.

Results and Discussion

Theoretical models

In the literature, there are several studies which treat the mathematical models of correlation between the properties of fibres and that of the yarn. These models are different depending on the type of cotton and the type of yarn built. We cite a few examples of studies incurred in that regard [2].

Ring yarn tenacity (cN/tex) = 0,31UR (%) + 0,80S (g/tex) - 1,1E (%) - 0,73M + 0,062T (tex) + 0,35α (English) - 21, 8 [3]. (1)

Ring yarn of 12 tex count and twist coefficients of 52,6 and 47,8 tr/cm.tex

Ring yarn tenacity (cN/tex) = -200,47 + 0,904Rd (%) + 0,257A (mtex) – 1,294Mat + 0,389S (g/tex) + 3,310α (tr/cm.tex) [4]. (2)

Ring yarn of 27 tex count and twist coefficients of 52,6 and 47,8 tr/cm.tex

Ring yarn tenacity (cN/tex) = -39,221 + 0,392S (g/tex) – 1,746E (%) + 3,908α (tr/cm.tex) [4] (3)

Ring yarn elongation at fracture = - 8.94 – 0.125S + 0.139E + 3.993UHML + 0.263UI – 0.832M – 0.022Rd – 0.143(b+) – 0.063Ne (English) [1] (4)

SCI = -414.67+2.9S – 9.32M + 49.17UHML + 4.74UI + 0.65(Rd) + 0.36(b+) (5)

Fibre and elastane properties	Minimum	Maximum
Cotton breaking strength (cN/tex)	29	34
Cotton breaking elongation (%)	6	7
Cotton length (mm)	29	34
Micronaire (fineness) (μg/inch)	4	4.2
Lycra count (dtex)	22	78
Lycra ratio (%)	3.57	11.33
Yarn count (Tex)	33.33	11.76
Nm	30	85
Yarn twist (Turns/m)	655	1050

Table 1: Summary statistics for fibre and yarn properties.

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Lycra Count (dtex)	Lycra ratio (%)	Cotton strength (cN/tex)	Cotton elongation (%)	Length Cotton (mm)	Micronaire (µg/inch)	Nm	Twist (turns/m)
44	3,57	34	7	34	4,2	30	655
78	7,58	29	7	29	4	34	734
44	5,33	29	7	29	4	40	813
22	3,67	29	7	29	4	50	918
44	9,07	29	6	34	t4	68	1047
44	4,88	29	6	34	4,2	70	1050
44	11,33	34	6	34	4,2	85	1022

Table 2: Some yarns properties with their fibre properties.

Nm	Twist (turns/m)	Tenacity (cN/tex)	$CV_{Tenacity}$ (%)	Elongation (%)	$CV_{Elongation}$ (%)
30	655	30,24	2,70	15,45	2,27
34	734	15,98	7,60	8,23	7,42
40	813	16,27	8,80	6	8,29
50	918	16,52	6,39	5,46	7,05
68	1047	17,27	8,51	8,85	9,63
70	1050	17,02	6,87	6,96	5,24
85	1022	14,97	5,67	6,38	6,20

Table 3: Tenacity and elongation of core spun yarns after tensile tests.

Nm	Lycra ratio (%)	Tenacity (cN/tex)	$CV_{Tenacity}$ (%)	Elongation (%)	$CV_{Elongation}$ (%)	Theoretical model (Tenacity)	Theoretical model (Elongation)
30	3,57	30,24	2,70	15,45	2,27	30,46	15,06
34	7,58	15,98	7,60	8,23	7,42	16,48	7,82
40	5,33	16,27	8,80	6	8,29	16,09	5,45
50	3,67	16,52	6,39	5,46	7,05	17,22	4,98
68	9,07	17,27	8,51	8,85	9,63	17,62	8,23
70	4,88	17,02	6,87	6,96	5,24	17,33	6,33
85	11,33	14,97	5,67	6,38	6,20	15,37	5,78

Table 4: Comparisons between theoretical models and experimental values.

Rotor yarn tenacity (cN/tex) = -18.936 + 0.406(b+) + 0.131A - 0.764Mat + 0.184S - 0.802E +1.570α -0.114UR [4] (6)

With UR: uniformity ratio, S: tenacity of fibres, E: lengthening of fibres, M: Micronaire index, T: yarn linear density, α: twist factor, Rd: reflexion, A: fineness of fibres, Mat: maturity, SL 2,5%: span length 2,5%, UI: uniformity index, UHML: upper half mean length and b+: Index of yellow [2].

After achieving the tensile tests on all cotton core spun yarn with elastane, we record the values of tenacity and elongation shown in table 3.

So we can know the impact of each parameter on the two model outputs Searched.

We used the statistical software Minitab (Minitab® 16.1.0) to see the different possible interactions that are shown in figure 1, and also to identify the degree of influence of each parameter shown in figure 2.

Interactions plot creates a single interaction plot for two factors. An interactions plot is a plot of means for each level of a factor with the level of a second factor held constant. Interactions plots are useful for judging the presence of interaction.

Interaction is present when the response at a factor level depends upon the levels of other factors. Parallel lines in an interactions plot indicate no interaction. The greater the departure of the lines from the parallel state, the higher the degree of interaction.

On figure 1 illustrating the possible interactions between different parameters, we distinguish that there is interaction between cotton strength and cotton elongation and another interaction between cotton elongation and micronaire. So, following these two interactions, the parameters cotton elongation and micronaire can be neglected compared to cotton strength in the proposed model.

The Nm seems to have a slight effect on the core spun yarn tenacity between Nm34 to Nm85, but a considerable effect between Nm30 and

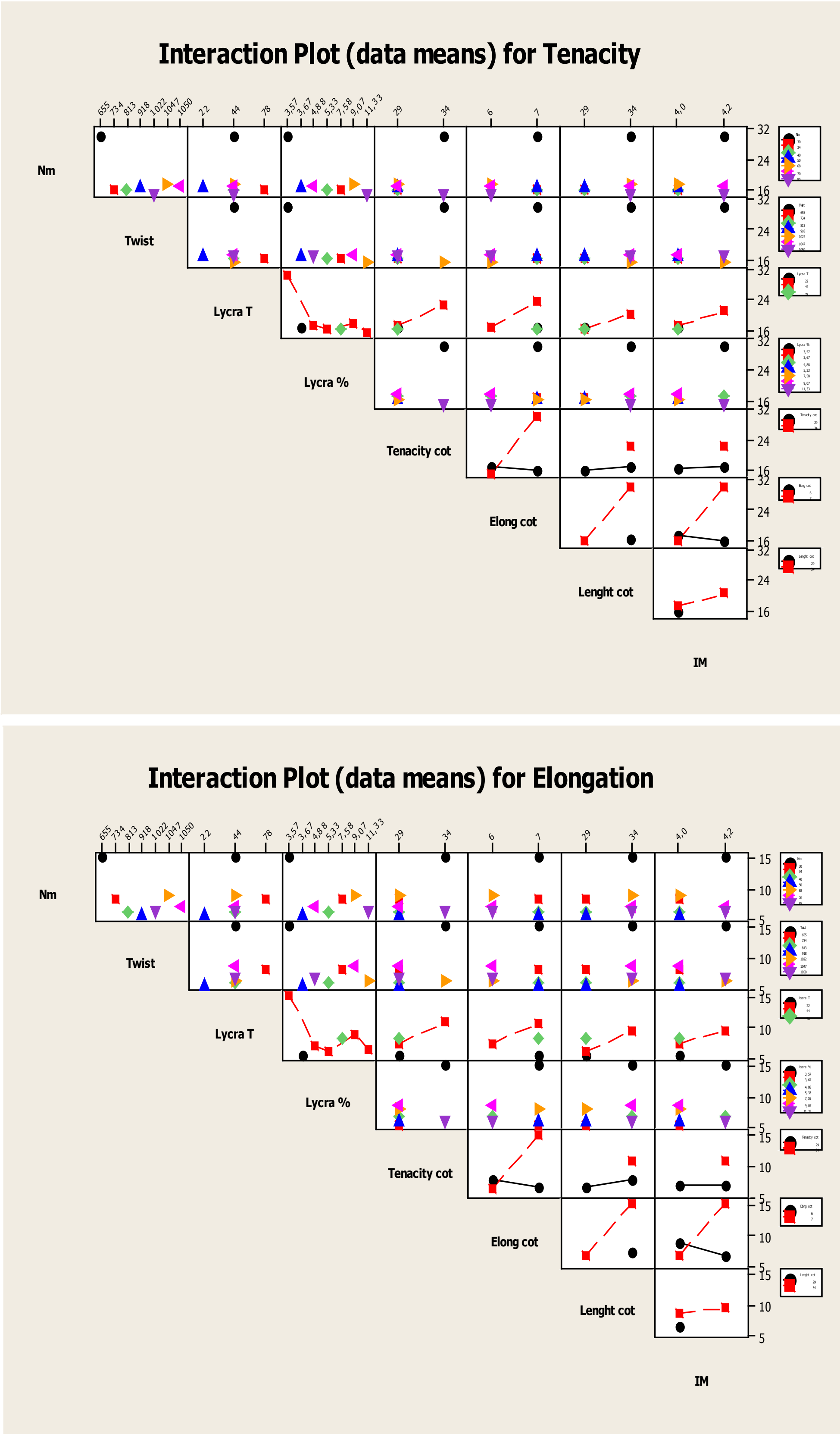

Figure 1: Parameters interaction plot for tenacity and elongation.

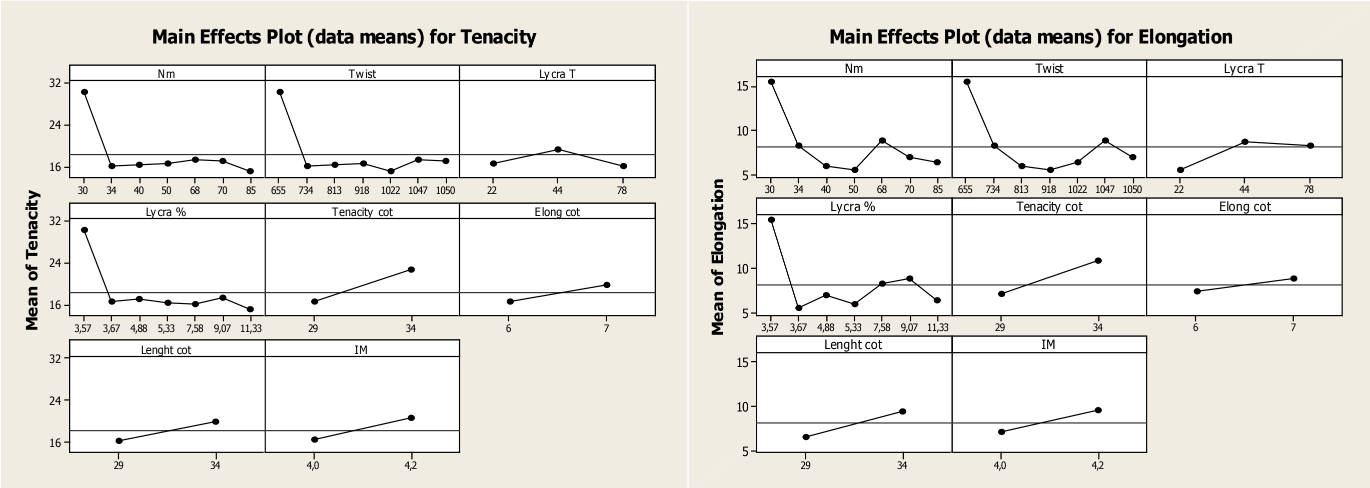

Figure 2: Main effects plot of different parameters for tenacity and elongation.

Nm34. It's the same things for twist and Lycra ratio. For the other parameters, cotton breaking strength, cotton breaking elongation, cotton length and micronaire have a medium effect on the core spun yarn tenacity and elongation. Finally, the parameter Lycra count has a positive and negative effect, but in 44 dtex, tenacity and elongation have the maximum value respectively 17.27 and 8.85.

The results of this study give us the following mathematical equations and comparisons between theoretical models and experimental values are shown in table 4.

The tenacity model equation is written: Tenacity (cN/tex) = -257,158 -1,491*Nm + 0,193*Twist + 0,230*Lycra count -0,504*Lycra ratio + 5,812*Cotton strength [R^2 =0.997] (7)

The elongation model equation is written: Elongation (%) = -214,559 -1,227*Nm + 0,159*Twist + 0,224*Lycra count -1,874E-02*Lycra ratio + 4,485*Cotton strength [R^2 =0.997] (8)

With R^2: the coefficient of determination of linear regression and of decision of the relationship among the different parameters.

The proposed models give good results by comparing the answers with the experimental results seen that R^2 is raised. By comparing these models with Hunter's models, Ramy and Majundar, we notice that all the models are linear and that they present almost the same parameters concerning cotton fibres, but in the model proposed in our case we have to try to integrate the properties of the thread to know Nm, twist and characteristics of the core elastane which influence directly the regulations of machines. Finally, the proposed model is valid in a large domain for Nm (30-85), twisting (655-1050), the Lycra count (22-78), the percentage of Lycra (3.57-11.33) and the cotton strength (29-34).

Rheological models

From several research tasks, the behaviour of yarns (cotton, viscose, polyester, polyamide, rayon and polyester/cotton mixtures) has good correlations with the model of L.Vangheluwe (1993) based on the model of Maxwell (the viscoelastic behaviour of these yarns) who is put in parallel with a nonlinear spring, represented in these following equation 9 and figure 3.

$$\sigma(\varepsilon)=0,5 + A(1-e^{-B\varepsilon})+D\varepsilon^2 \quad (9)$$

With A, B, C, D and F are the constants to be estimated according to the behaviour of the textile yarns [5].

Another rheological model of L.Vangheluwe but modified is proposed to find out the behaviour of yarns starting from the tensile tests [5].

$$\sigma(\varepsilon)=0,5+1,28(1-e^{-B\varepsilon})+D\varepsilon^{\frac{2}{3}} \quad (10)$$

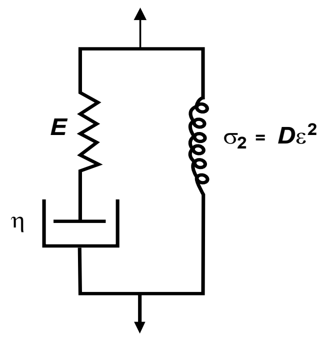

Figure 3: L.Vangheluwe model.

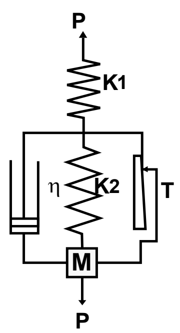

Figure 4: Zurek model.

Nm	Twist (Turns/m)	Lycra count (dtex)	Rheological models	A	B	C	D	F
30	655	44	**L.Vangheluwe**	1315,56	0,002017		-0,102169	
			L.Vangheluwe modified	1,28	0,0469526		0,824069	
			Zurek	4,56092	-606,384	0,007021	0,144609	
			Manich	-0,063023	-0,287493	0,492951	1,01458	0,83020
34	734	78	**L.Vangheluwe**	164,139	0,001129		0,02946	
			L.Vangheluwe modified	1,28	0,058656		0,661173	
			Zurek	0,79442	-3,78354	0,192176	0,078734	
			Manich	0,319441	0,328302	0,128451	5,825 10^{-8}	1,5581
68	1047	44	**L.Vangheluwe**	61,6214	0,003891		0,000634	
			L.Vangheluwe modified	1,28	0,066131		0,320235	
			Zurek	0,022196	-27,9558	-0,007520	0,017291	
			Manich	0,05738	3,28676	0,207089	0,726904	1,05914
85	1022	44	**L.Vangheluwe**	103,119	0,002311		0,001526	
			L.Vangheluwe modified	1,28	0,099116		0,231443	
			Zurek	0,251601	-0,032477	1,41338	0,011375	
			Manich	1,25518	0,007901	0,226856	3,639 10^{-9}	1,04227

Table 5: Determination of the coefficients of the rheological models.

Another model was established based on the model of Vangheluwe and by introducing the results of the tests of relaxation. The model of Manich [5] is represented by the following equation11 [5].

$$\sigma(\varepsilon)=0,5+A(1\text{-}e^{-B\,\varepsilon^{D}})+C\varepsilon^{F} \qquad (11)$$

Another model was established by Zurek (1975) for textile fibres represented in the following figure 4 and equation 12:

$$\sigma(\varepsilon)=A\varepsilon+B(1-e^{-C\varepsilon})+De^{-C\varepsilon} \qquad (12)$$

When core spun yarn is mechanically deformed, three regions can be defined according to the stress-strain curve shape: The initial region, the yield region, and the strengthening zone. In the initial region, the fibres constituting core spun yarn support the strain, and the core spun yarn behaves like an elastic solid. In the yield region, where lengthening is slower, the fibers start to slip between them into yarn as we increase the tension, with a speed proportional to the relaxation time. The core spun yarn behaves like a plastic material. In the strengthening zone, a new configuration of core spun yarn occurs, where the slope decreases, therefore the yarn stretches more easily and the fibers continue to slip, and the core spun yarn becomes more resistant to deformation and the elastane filament resists until the rupture of yarn.

All the rheological models include terms that define the three regions.

After using Matlab (MATLAB® 7.6) and making several iterations, we find all coefficients of all models by optimizing the experimental values that are represented on the following table 5:

After calculating the different coefficients A, B, C, D and F of different rheological models studied, we chose to study Nm30, Nm34, Nm68 and Nm85 to see the differences in the behaviour of these models compared to tensile tests. From these values, we distinguish the modified Vangheluwe model remains almost unchanged as we vary the Nm, twist and Lycra count, from the other figures we notice that it is not well adapted to the behaviour of cotton core spun yarn with elastane.

For the other three rheological models, when we change the Nm68 to Nm85, or when changing the twist of 655 to 1047 turns/m, or when changing the Lycra count from 44 to 78 dtex, we note that the model behaviour changes when the other parameters remain fixed. What explains the influence of these three parameters on the tenacity and elongation of core spun yarn with elastane.

There are also curves of optimization, which are represented in the following figures 5, 6, 7 and 8:

The viscoelastic models used for Force-Elongation curves fit of core spun yarns give good results. Bearing in mind the very high values of coefficient ratios and equation R^2, the L.Vangheluwe model yielded the

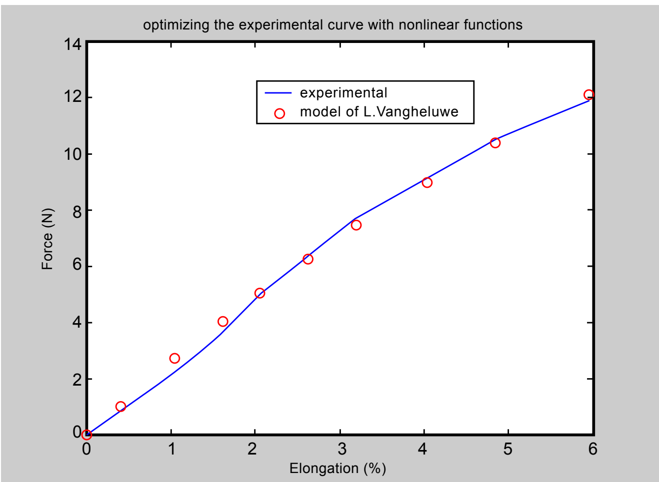

Figure 5: Correlation between the mechanical behaviour of the core spun yarn (Nm 30 with lycra 44 and twist of 655turns/m) and the model of L.Vangheluwe during the tensile test (R^2=0,994).

best results for core spun yarn with elastane fitting and Manich's model with relaxation data the best results for core spun yarn fitting.

Conclusions

There is some parameters which influence considerably more than others on the answer of all the models. We can build another model more powerful than the others already existing.

With the tensile tests carried out on some core spun yarns with elastane, we could find the exact coefficients of the nonlinear equations of these rheological models which are well adapted to the answers of the yarns tensile tests than it is with graphic methods or methods of optimization of the experimental curves with the curves given by these nonlinear models of behaviour. We found out the models which simulate the exact behaviour of our core spun yarns. So, it remains to choose one of these models to be able to continue our study to calculate E and η parameters for each model, to show the effect of each parameter related to cotton fibres and elastane on the behaviour of these models.

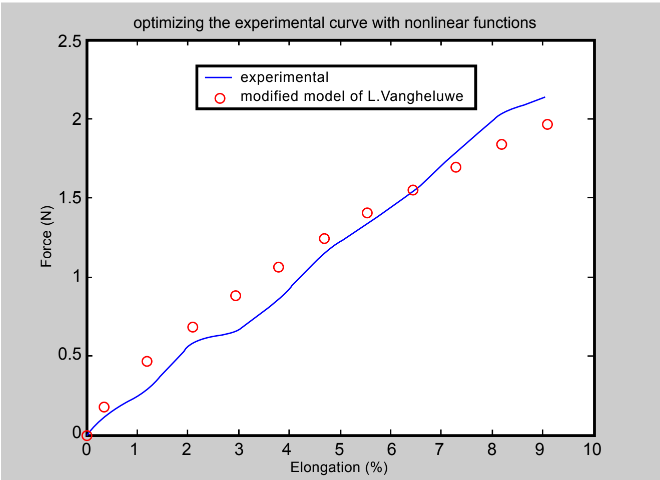

Figure 6: Correlation between the mechanical behaviour of the core spun yarn (Nm 68 with lycra 44 and twist of 1047turns/m) and the modified model of L.Vangheluwe during the tensile test (R^2=0,875).

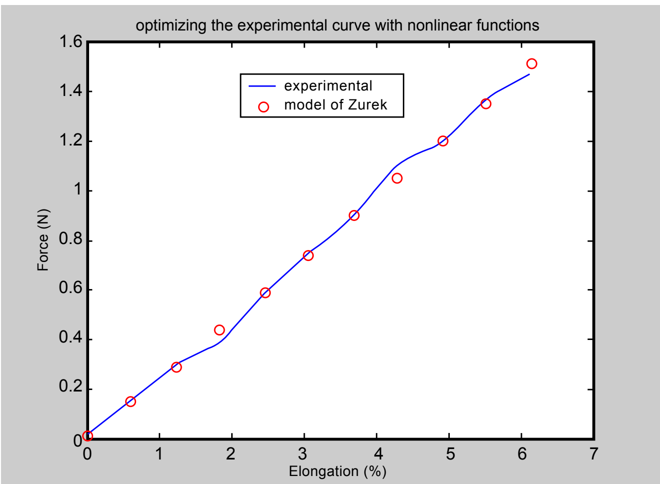

Figure 7: Correlation between the mechanical behaviour of the core-spun yarn (Nm 85 with lycra 44 and twist of 1022turns/m) and the model of Zurek during the tensile test (R^2=0,905).

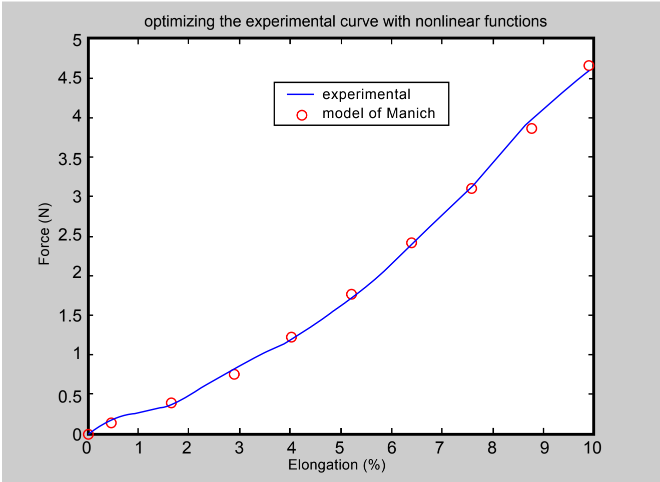

Figure 8: Correlation between the mechanical behaviour of the core-spun yarn with elastane (Nm 34 with lycra 78 and twist of 734turns/m) and the model of Manich during the tensile test (R^2=0,993).

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