МОДЕЛИРАНЕ НА МЕХАНИЧНИТЕ СВОЙСТВА НА ЕДИНИЧНИ И ГРУПИРАНИ ПАМУЧНИ ВЛАКНА С ИЗПОЛЗВАНЕ НА АНАЛОГОВИ МОДЕЛИ

Уафа МАХЖУБ[1,2], Жан-Ив ДРЕАН[1,2], Омар АРЗАЛА[1,2] и Жан-Пол ГУРЛО[3]
[1]Университет на Южен Елзас, Лаборатория по физика и механика на текстилите
Ул. Алфред Вернер 11, Ф-38093 Мюлуза, Франция
[2]Университет на Страсбург, Франция
CIRAD (Център за международно сътрудничество за земеделско изследователско развитие),
авеню Агрополис, 34398 Монпелие, Франция
e-mail: Jean-yves.drean@uha.fr

SINGLE AND BUNDLE COTTON FIBRES MECHANICAL PROPERTIES MODELLING USING ANALOGICAL MODELS

W. MAHJOUB[1,2], J.-Y. DREAN[1,2], O. HARZALLAH[1,2] and J.-P. GOURLOT[3]
[1] Université de Haute Alsace, Laboratoire de Physique et Mécanique Textiles LPMT EA 4365,
68100 Mulhouse - France.
[2] Université de Strasbourg, France
[3] Cirad (Centre de coopération Internationale en Recherche Agronomique pour le Développement),
Avenue Agropolis, 34398 Montpellier, France

ABSTRACT

Among the many properties of cotton fibers, mechanical ones are the most important indicators to select the proper fibers for specified textile end use applications. Either the single cotton fibers properties or the spun yarn ones are related not only to their tensile properties, but also to the time dependent ones such as the creep and the stress relaxation. In addition, the frictional behavior of cotton fibers greatly influences their processing, their performance and the performance of the final product.

In this paper, two methods of cotton fibers testing are presented: single fibers and bundles. Three different types of cotton fibers were studied, having different physical properties (maturity, fineness, micronaire, length, tenacity etc.). We show that the creep behavior of cotton fibers can be assimilated to a Voigt model in series with a spring and that the difference in the behavior between the single fibers and bundles is related to the inter-fiber friction.

Keywords: *Bundles, cotton, inter-fiber friction, modelling, single fibers.*

I. INTRODUCTION

Studying the behavior and the relationships between single and bundle cotton fibers mechanical properties is very crucial. In fact, single fibers are the fundamental units of a span yarn [1]. Any study of a yarn model must include the parameters of the fibers and their relationships. In general, fibers physical properties (fineness, diameter, shape factor and length) contribute to yarn strength through two factors: fiber strength and inter-fiber friction. For this purpose, we aim to analogically model the cotton fibers relationships and to study the inter-fiber friction in the bundle of cotton fibers.

II. METHODS AND PROCEDURES

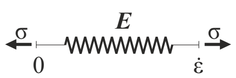
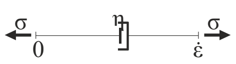
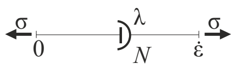
A. Rheological modelling

Cotton fibers contain natural polymers (90% of cellulose), and therefore they exhibit a viscoelastic behavior [2]. This mechanical behavior can be adjusted using analogical models consisting of elements such as Hook springs, Newton dashpots, as shown in ***table 1***, which could simulate the mechanical behavior of the material under mechanical stress when correctly combined.

These models are very useful to clarify how fiber behaves. They can be assembled both in series or in parallel or in mixed groups [3]. Thus, more complex mechanical responses can be simulated to illustrate the behavior of the material submitted to static test (tensile test) or a time dependent one (creep or stress relaxation tests).

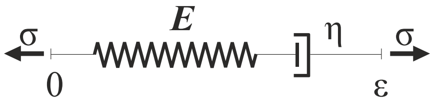
Table 1

General analogical models

Analogical model	Equation	Mechanical element
	$\sigma = E\,\varepsilon$ Where: σ is the stress, ε is the strain and E is Young's modulus	Spring
	$\sigma = \eta\,\dot\varepsilon$ Where: σ is the stress, $\dot\varepsilon$ is the strain rate, and η is the viscous coefficient	Dashpot
	$\sigma = \lambda\,\dot\varepsilon^{1/N}$ Where: λ is a constant related to the material used, and N is a constant characterizing the flow	

Creep and stress relaxation tests demonstrate the viscoelastic characteristics. In creep test, a constant stress is maintained on a specimen while its deformation is monitored as a function of time and deformation increases with the time. In stress relaxation test, a constant deformation is maintained while the stress on the specimen is monitored as a function of time, and stress decreases with time. The classical viscoelastic constitutive models are represented by Maxwell and Voight models [4] using springs and dashpots to simulate elasticity and viscosity respectively.

- Maxwell model:



Equation:

$$\dot\varepsilon = \dot\varepsilon_{elastic} + \dot\varepsilon_{elastic} = \frac{\dot\sigma}{E} + \frac{\sigma}{\eta} \quad (1)$$

Response for creep test:

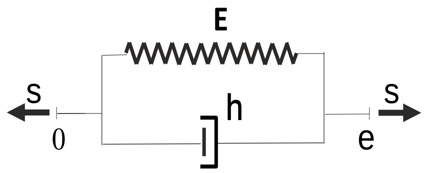
$$\varepsilon = \frac{\sigma_0}{E} + \frac{\sigma_0}{\eta}\, t \quad (2)$$

Table 2

Cottons different properties detetmined with afis

Cotton	L(n) [mm]	L(w) [mm]	SFC(n) [%]	SFC(w) [%]	Fineness [mTex]	Maturity
C07	24	28,3	14,4	4	148	0,9
C42	19,2	23,9	24,9	9,1	152	0,83
C55	24,5	28,7	13,5	3,9	166	0,92

- Voigt model:



Equation:

$$\dot\varepsilon = \dot\varepsilon_{elastic} + \dot\varepsilon_{elastic} = \frac{\dot\sigma}{E} + \frac{\sigma}{\eta} \quad (3)$$

Response for creep test:

$$\varepsilon(t) = \frac{\sigma_0}{E}\left(1- e^{(-E.\frac{t}{\eta})}\right) \quad (4)$$

B. Experimental details

In our study, we worked on the tensile and the creep behavior of the single and bundle cotton fibers. Three different types of cotton fibers were studied. These cottons were chosen from a list of twelve cottons covering a large panel of varieties and physical properties.

Prior to testing, all cotton samples were conditioned for at least 48 hours at 65± 2% of relative humidity (*RH%*) and 21± 1°C of temperature (*T*) of the surrounding air. In fact, these factors are very important because any change can have a significant effect on the values of strength.

For measuring single fibers properties, Favimat (Textechno Herbert Stein GmbH and Co. KG, Möchengladbach, Germany) was used. The typical testing methods of the Favimat are the static tensile test, linear-density (fineness) measurement, and measure-ment of crimp extension, crimp stability as well as number of crimps. Tests were carried out using the following parameters:

Test speed: 5mm/min
Gauge length: 15mm
Sensor: 210 cN
Pretension: 0.06 cN/Tex
Nominal linear density: 10 dTex

For bundle testing, Pressley clamps were used with a special spacer of 15 mm for realizing test in a MTS dynamometer (***Figure 1***).

Tests were carried out using the following parameters:

Test speed: 5mm/min
Gauge length: 15mm
Sensor: 2 kN
Test duration: 20min

Figure 1 Specific attachments for the MTS device and the Pressley jaws; bundle tests.

Tensile fracture of cotton fiber was examined by a scanning electron microscope (SEM). Samples were gold sputtered in vacuum condition to obtain a better electrical conductivity. The magnification is set at 2500.

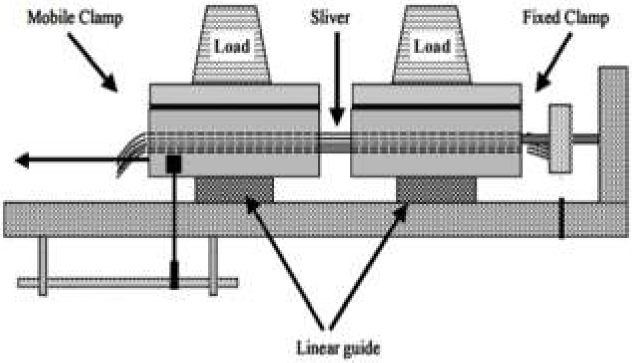


Figure 2 Static Friction Tester (SFT)

The Static Friction Tester is used to determine the friction coefficient, this device is composed of two identical carriages; one of them is fixed, whereas the second is moving through a linear guide. A piece of sliver is put down in the channel of the two carriages, which are initially in zero gage position. The sliver is compressed with the upper carriage sides where two identical weights are loaded. The tests carried out are a series of five loads varying from 1 to 5 kN

The friction measuring device is based on the principle of measuring the force required to break a sliver.

According to the studies related to the friction, it is necessary to control the normal force during relative movement of bodies in contact.

Therefore the fibers in the sliver are tightened using a uniform normal load, So the fibers in the sliver moves by simply pulling the sliver axially with two identical and opposite forces, The force that the fibers develop to oppose their relative sliding force is the inter-fiber friction.

The data obtained from SFT gives rise to the following equation to get the inter-fiber friction results:

$$\frac{F}{N_f} = k\left(\frac{W}{N_f}\right)^a \qquad (5)$$

Where: F - the frictional resistance force,
N_f - the number of fibers in sliver cross-section,
W - the perpendicular compression force on fiber,
K, a - the coefficients that characterize friction.

III. RESULTS AND DISCUSSIONS

A. Physical and mechanical properties

The figures 3 and 4 show the summary of the results obtained by the Favimat apparatus on the single cotton fibers for the three varieties. We can conduct that there is a negative relation between the length of fibers and their linear densities and a positive relation between length and the tenacity.

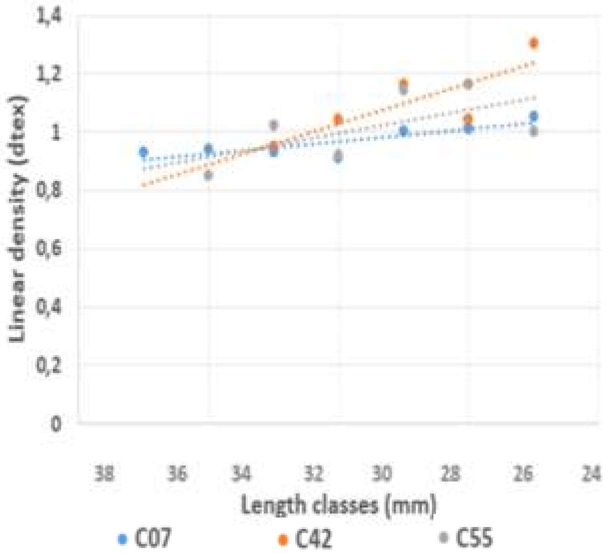


Figure 3 The linear density vs. length of the single fibers.

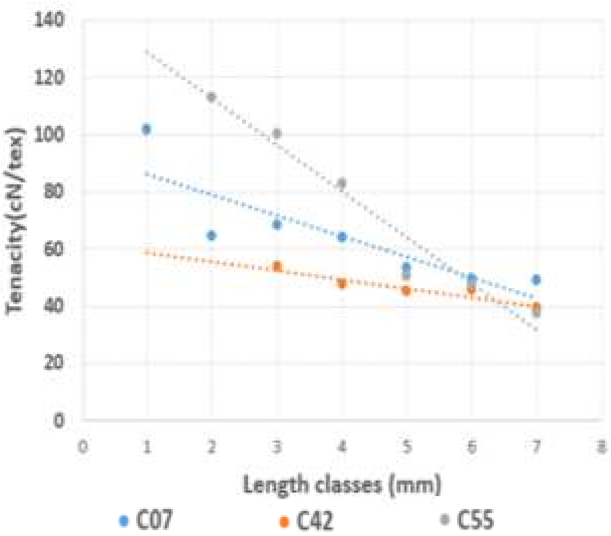


Figure 4 The Tenacity vs. length of the single fibers.

B. Models elaboration

Tensile test allowed us to determine parameters such as Young modulus (E), work of rupture and tenacity. In fact, during the tensile test, the cotton fibers obey equation 6 and can physically be represented by an ideal Hookean spring, with stress proportional to strain.

$$\sigma = E\,\varepsilon \tag{6}$$

The SEM image in ***Figure 5***, illustrates the rupture behavior of the cotton fiber. We can observe that the break occurred adjacent to a reversal, and the splitting was due to the untwisting effects. Eventually a tear developed along the fiber to join up the split, follows the helical path of the fibrils around the fiber [5].

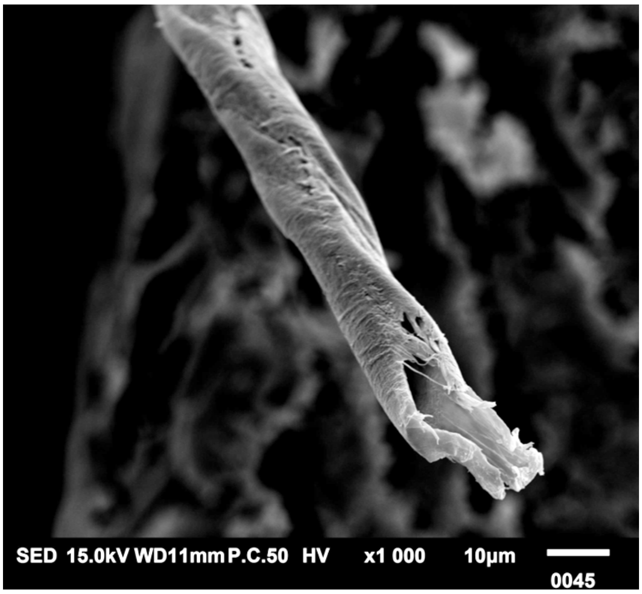


Figure 5 SEM image of a cotton fiber tensile fracture.

Creep is a time-dependent deformation under a certain applied load. Several hypotheses were studied in order to understand the cotton fiber behavior to the creep test and to model it into an analogical way. One of them is to divide the experimental creep behavior result into two parts; the first one is assimilated to a dashpot and the second one to a Voigt model.

The following equations represent respectively their response to the creep test.

$$\varepsilon_{dashpot}(t) = \frac{\sigma_0}{\eta_1}\,t \tag{7}$$

$$\varepsilon_{Voigt}(t) = \frac{\sigma_0}{E}\left(1 - e^{(-E.\frac{t}{\eta})}\right) \tag{8}$$

Figure 6 shows the response of the total model to an applied stress σ_0 for a single fiber creep test. The fiber length group was 30 to 32 mm. We can observe a fast-increase part (part 1) explained by the fact that the stress was at first carried entirely by the viscous element of the dashpot (η_1). The second part (part 2), characterized by a very slight increase explains the elastic element (E) in the continuous elongation of the viscous element (η_2). The transition time between the two parts represents the creep time.

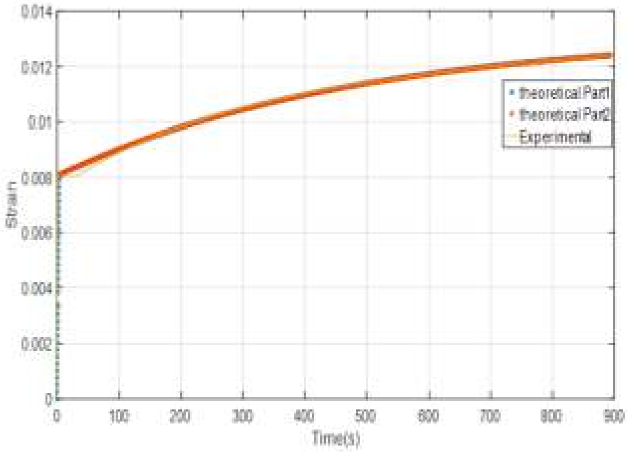


Figure 6 Single fiber creep test result and the model one based on real experimental data.

For the bundle tests, about 5mg of parallel cotton fibers of each length class were tested several times and the results were found to be repeatable. For instance, ***Figure 7*** shows both the practical and the theoretical results. We can notice that with the same cotton variety and the same length class, the second part of the model fit to creep test one.

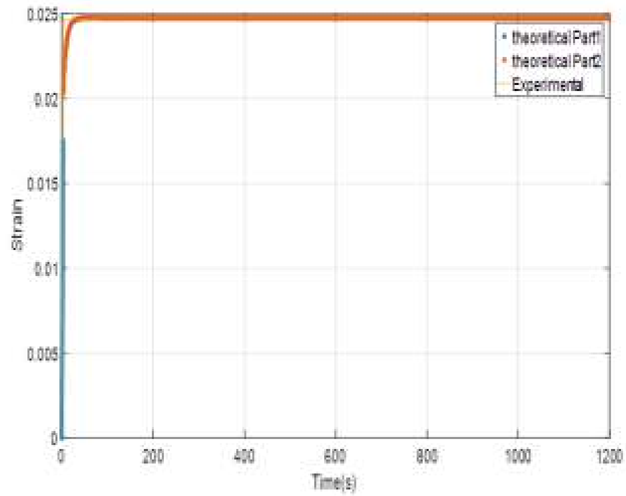


Figure 7 Bundles creep test result and the model one based on real experimental data.

C. Inter-fiber friction

The experimental results have been evaluated with a program that we develop via Matlab. Theoretical parameters have been then determined in order to fit the best with the experimental results.

In this aim, for the first part, the viscosity $\boldsymbol{\eta_1}$ have been determined. Moreover, for the second part, the viscosity $\boldsymbol{\eta_2}$ and the modulus ***E*** have been determined.

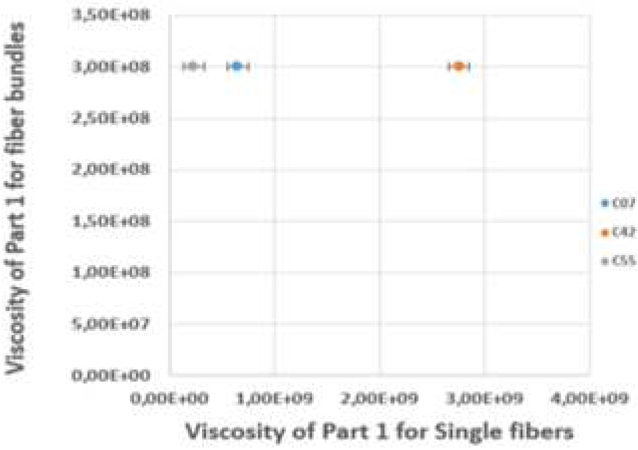


Figure 8 Bundle vs. Single cotton viscosity for the first part of the model.

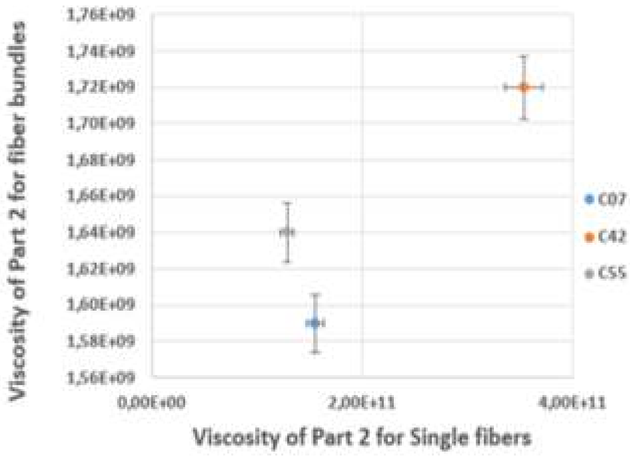


Figure 9 Bundle vs. Single cotton viscosity for the second part of the model.

Table 3

Friction coefficient K for the three cotton varieties

	K
C07	0,5668
C42	0,6345
C55	0,5755

The results determined with the SFT device show that both cottons C07 and C55 have approximatively the same friction coefficient compared with cotton C42

In fact, C42 is more immature than C42 and C55. There is more contact points in his surface, this issue explains the higher value of K.

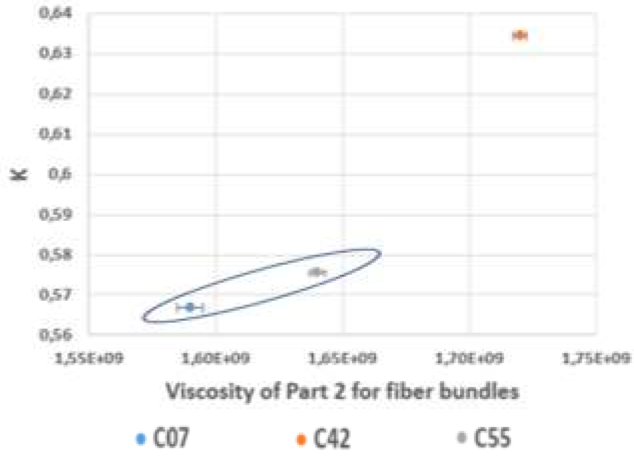


Figure 10 Friction coefficient K vs. the bundle cotton viscosity for the second part of the model.

Figure 10 confirms our hypothesis. In fact, C42 have remarkable differences with the other cottons, taking in account the variation of k compared with the viscosity values.

IV. CONCLUSIONS

In this research, we study the single and bundle cotton fiber mechanical properties by modelling their creep behavior. We determine and demonstrate the influence of inter-fiber friction. We show that this latter influences the creep behavior of bundles.

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