Single and bundle cotton fibers testing; Friction component

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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 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.

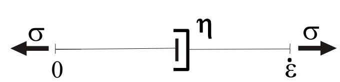
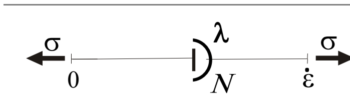
II. METHODS AND PROCEDURES

A. Analogical 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 I
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*:

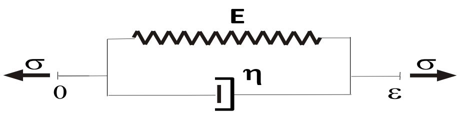
Equation:

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

Response for creep test:

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

– *Voigt model*:



Equation:

$$\sigma = \sigma_{elastic} + \sigma_{viscous} = \eta\, \dot{\varepsilon} + E\, \varepsilon \quad (3)$$

Response for creep test:

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

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. In this paper, only the results of the [30-32] mm length group will be presented.

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 measurement 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

Fig. 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.

An atomic force microscope (AFM) with a software to calculate the surface roughness was used to analyze the surface topology and roughness.

III. Results and Discussions

A. 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 5 and can physically be represented by an ideal Hookean spring, with stress proportional to strain.

$$\sigma = E\, \varepsilon \quad (5)$$

The SEM image, as shown in figure 2, 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, which follows the helical path of the fibrils around the fiber [5].

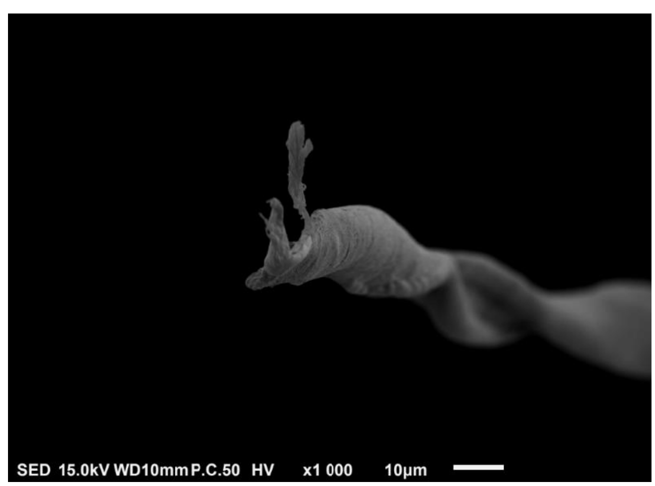


Fig. 2. SEM image of a cotton fiber tensile fracture.

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.

$$\varepsilon_{dashpot}(t) = \frac{\sigma_0}{\eta_1}\, t \qquad (6)$$

$$\varepsilon_{Voigt}(t) = \frac{\sigma_0}{E}\left(1 - e^{\left(-E.\frac{t}{\eta_2}\right)}\right) \qquad (7)$$

Figure 3 shows the response of the total model to an applied stress σ_0 for a single fiber creep test (the result shown is the average of ten tests) . 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 constant, t_c, which is equals to $\frac{\eta_2}{E}$, where η_2 is the viscosity and E is the Initial modulus given by the tensile test at a given constant rate of extension.

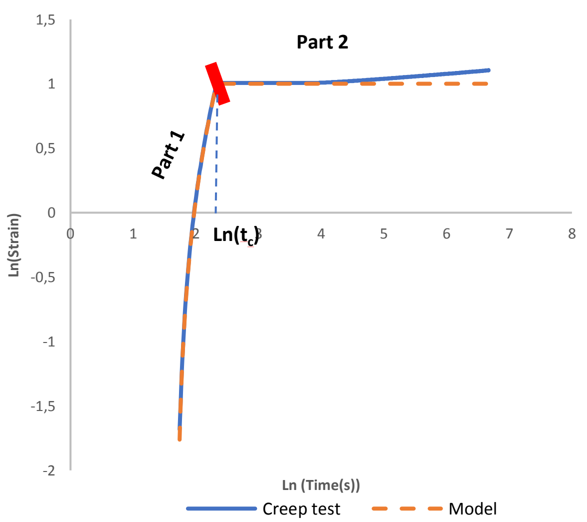


Fig. 3. Single fiber creep test result and the model one based on real experimental data.. Ln (strain) as a function of Ln (time).

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 4 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 do not exactly fit to creep test one.

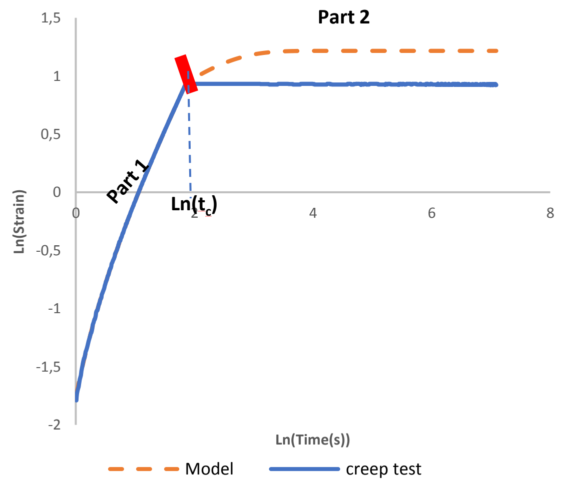


Fig. 4. Bundles creep test result and the model one based on real experimental data. Ln (strain) as a function of Ln (time).

B. Inter-fiber friction

We conceived that the inter-fiber friction in the bundles caused this remarkable difference. In fact, the morphology of the cotton fiber is heterogeneous, and this increases the bundles contact points and thus the friction. This latter modifies the viscosity of the Voigt part, which changes the model.

To understand this difference, we had a reverse reasoning. We tried to increase the inter-fiber friction to evaluate the analogical model then. The method used was to coat the cotton bundles with a plasma treatment [6], which changed the cotton fibers surface chemistry. High purity argon (Ar) and oxygen (O_2) were used as received plasma. The plasma treatment was conducted with a power of 50W; pressure of 1mbar (0.8 $O_2 \rightarrow$ 1 Ar); 7 min duration.

AFM analysis result using the quantitative nanoscale mapping (QNM) peak force mode is shown in figures 5 and 6.

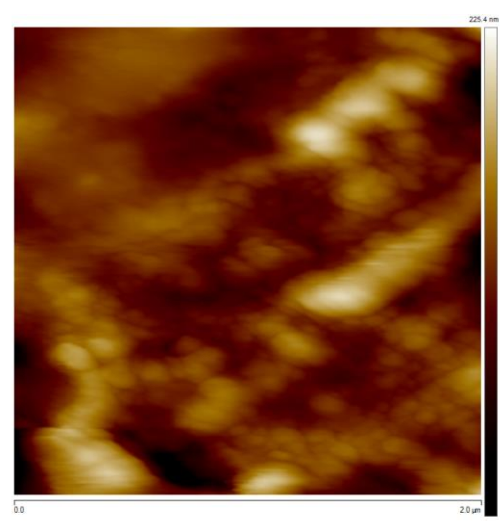


Fig. 5. AFM image; surface topology of plasma O_2/Ar treated cotton fiber.

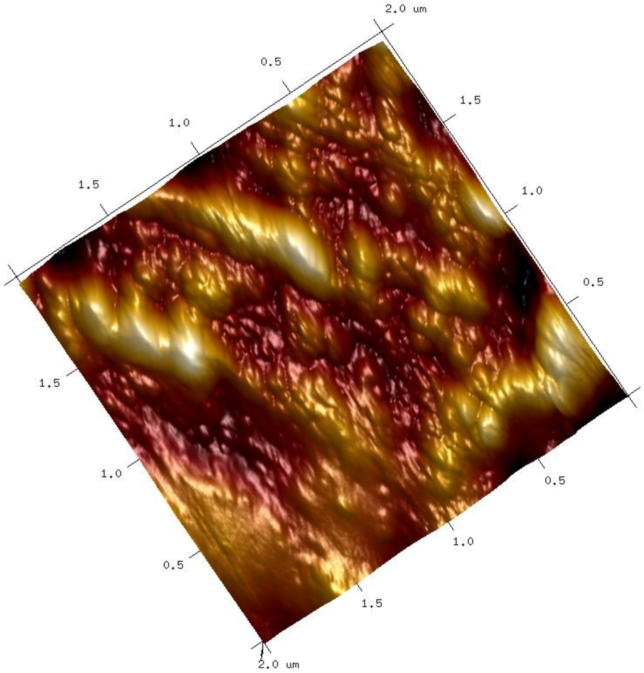


Fig. 6. 3D AFM image; surface topology of plasma O_2/Ar treated cotton fiber.

Over and above the difference observed in the AFM images, the roughness before and after the plasma treatment increases. Indeed, the value of Rq (Root Mean Square Roughness) went from 22.2nm without treatment to 42.4nm. after treatment.

The following figure confirms that the increase of the roughness increases the inter-fiber friction.

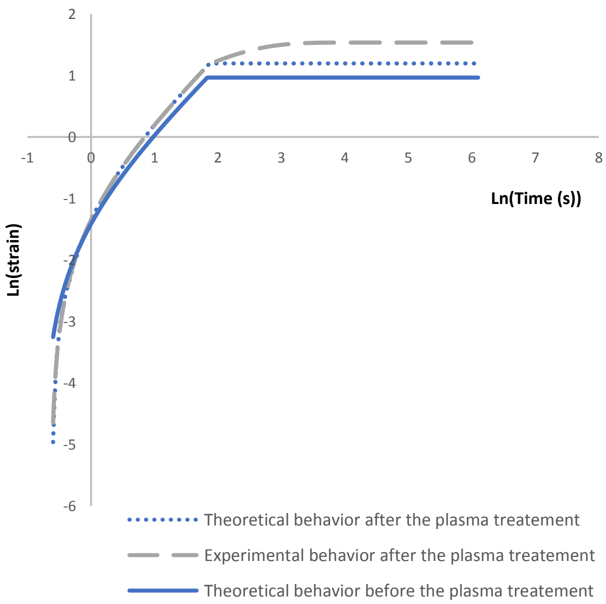


Fig. 7. Theoretical bundles creep behaviors before and after the plasma treatments compared to the experimental behavior after the plasma treatment. Ln (strain) as a function of Ln (time).

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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