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# A NONLINEAR VISCOELASTIC MODEL FOR DESCRIBING FABRIC WRINKLE RECOVERY BEHAVIOUR

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**ABSTRACT**

The main objective of this paper is to study and model the relaxation behaviour of fabric wrinkle recovery. Based on the viscoelasticity theory of textile materials and in order to describe the viscoelastic behaviour of wrinkle recovery, we proposed a rheological model and we studied the correlation between the experimental and the theoretical creep-recovery curves. The creep-recovery equation of Burger's model describes well the relaxation behaviour of the wrinkle recovery according to the time. The proposed nonlinear viscoelastic model permitted us also to evaluate the components of elastic, viscoelastic and plastic deformation of the different wrinkled fabrics.

**KEYWORDS**

Fabric wrinkle recovery; rheological model; relaxation behaviour; creep-recovery.

## 1. INTRODUCTION

Textiles are usually subjected to a wide range of deformations such as bending, folding, creasing, and wrinkling, which may be added deliberately during manufacturing and care or produced by movement of the body during use. Adding wrinkles to a fabric can produce some desirable features as fashionable appearance, usefulness, and minimum care. But unintentionally developed, short, irregular wrinkles are unsightly.

The modelling of the fabrics wrinkling behaviour is fundamental in order to obtain a realist simulation especially in the wrinkling recovery of textile fabrics. Given that the deformation behaviour of a textile fabric is viscoelastic behaviour (Jeddi et al. 2003; Asvadi et al., 1994), the rheological modelling based on the viscoelasticity theory, which is a necessary physical property for fabrics for realistic deformation behaviour (Dong et al., 2003; Terzopoulos et al., 1988).

According to the literature, Vangheluwe et al. (Vangheluwe et al., 1995; 1997) modelled the viscoelastic behaviour of fabric while based on the generalized Maxwell model. Assuming that the textile fabric is elastic, other researchers have studied the textile fabrics creasing using a simple rheological model with two components; a linearly elastic element and a frictional element for modelling the crease recovery (Shi et al., 2009; 2000). Moreover, based on the values of the crease recovery angle, Fridrichova et al. and Mihailović et al. (Fridrichova et al., 2011; Mihailović et al., 1995) have determined the components of elastic, viscoelastic and plastic deformation of different woven structures.

But it should be mentioned that in the literature the rheological modelling of wrinkling just describes the phenomenon of bidirectional creasing generated by the crease recovery tester. Therefore, we proposed in

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this paper a four-element model to study the recovery behaviour of multidirectional fabric’s wrinkling generated by the French method "cylindre creux". We developed the rheological model to describe the viscoelastic behaviour during wrinkling recovery that permitted to determine the components of elastic, viscoelastic and plastic deformation.

## 2. MATERIALS AND METHODS

### 2.1. Experimental methodology

In order to study the woven fabric’s wrinkling behaviour, the relaxation wrinkling test is carried out on specimens wrinkled by the "cylindre creux" test method according to the French standard (NF G 07-125, 1974). Indeed, the French method of evaluating fabric wrinkling consists in introducing a sample of cloth or knit, of prescribed dimensions, in a hollow cylinder, then submitting it during one minute to the static action of 750 g weight as shown in figure 1. This method produces a multidirectional and realistic wrinkling.

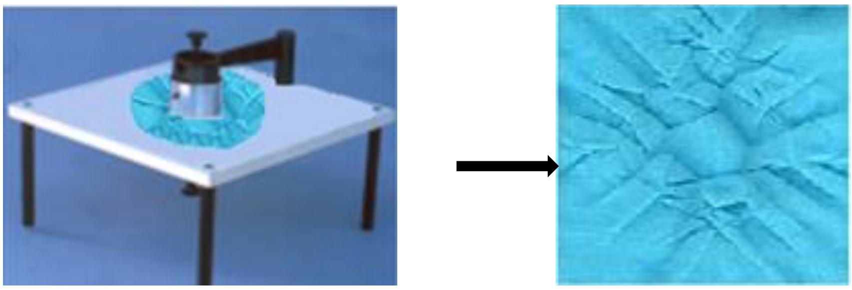

Figure 1: Generation of wrinkling by the "cylindre creux".

After removing the mass, the specimen is suspended by one side in the warp direction on the relaxation support shown in figure 2, so that the ends of specimen remote of 200 mm is suspended on a distance of 180 mm of relaxation support. (NF G 07-125, 1974).

The wrinkling evaluation that will be described later, is carried immediately after removing the wrinkled fabric from "cylindre creux", then after 1 min, 5 min, 10 min, 15 min, 30 min, 45 min, 60 min, 90 min, 120 min, 150 min and 180 min of relaxation in standard atmosphere fabric conditioning.

It should be noted that all experimental tests were carried out under standard atmosphere for conditioning and testing textiles, according to the standard ISO 139 (ISO 139, 2011) and all used specimens are conditioned in the standard atmosphere.

Figure 2: Relaxation support.

The wrinkling evaluation consists in evaluating the fabric wrinkling grade by the objective method developed using image analysis for assessing multidirectional fabric's wrinkling generated by the French method "cylindre creux" (Zaouali et al., 2010). In fact, after each relaxation time, each wrinkled fabric removed from the relaxation support was captured using a scanner. Then, "MATLAB" software was used to analyse each captured digital image of the wrinkled fabric.

The image analysis is used to define several wrinkles characteristics, such as wrinkle number (N), wrinkle surface roughness (R), wrinkle density (D), wrinkle length (L), and wrinkle height (H). These characteristics were measured to evaluate the fabric wrinkling grade (WR) estimated by the following equation (Zaouali et al., 2010):

$$WR = 6.91 + 0.051\,N - 0.186\,R - 0.117\,D - 0.074\,L - 0.140\,H \tag{1}$$

In order to study the fabric wrinkle recovery after relaxation test, we used fifty kinds of woven fabric having different wrinkle appearances. The used fabrics differ in weaves (plain, twill, satin). In fact, we used twenty plain fabrics, twenty twill fabrics and ten satin fabrics. Furthermore, these fabrics are made from different fibers or mixture of fibers, including fifteen cotton fabrics, fifteen polyester fabrics, fourteen fabrics made from mixture of cotton and polyester and six fabrics made from wool, linen and jute.

According to the literature, Hezavehi et al. and Zaouali et al. (Hezavehi et al., 2010; Zaouali et al., 2007) showed that the most influential characteristics on the wrinkling behaviour, are the weight, the thickness, the warp density and the weft density. These most influential characteristics on the wrinkling behaviour of different used fabrics are distributed over a large range of variation as shown in Table 1.

Table 1: Summary of some characteristics of different fabrics

| Parameters | Min | Max | Mean | CV (%) |
|---|---|---|---|---|
| **Weight (g/m$^2$)** | 53.7 | 400.8 | 172.33 | 39.54 |
| **Thickness (mm)** | 0.06 | 0.66 | 0.31 | 43.02 |
| **Warp density (picks/cm)** | 12 | 100 | 36.84 | 47.95 |
| **Weft density (ends/cm)** | 10 | 48 | 24.26 | 31.37 |

In the experiment, upon removing of the cylindrical metal mass (750 g), the fabric wrinkling grade is evaluated. When the weight is removed, the strain of the fabric changes with relaxation time, this is called creep-recovery behaviour. Therefore, the grade of the wrinkling is actually dependent on the strains of the fabric. Consequently, the wrinkle relaxation behaviour varying with relaxation time should be characterized according to the equations of creep-recovery behaviour of rheological models.

### 2.2. Rheological modelling

The deformation behaviour of a textile fabric is according to the viscoelasticity characteristics (Al-Gaadi et al., 2012, Asayesh et al., 2010). Therefore, we analysed the fabric wrinkling recovery behaviour during relaxation, using the viscoelasticity theory. The creep–recovery behaviour can be looked at as a combination of springs (elastic sections) and dashpots (viscous sections).

There are some common rheological models for mechanical analysis of textile materials. The simplest model is Maxwell's model. It is constituted by a series wound about a Hookean elasticity spring and a Newtonian viscosity dashpot. More complicated models are Kelvin-Voigt's model and Burger's model.

According to the literature, the fabric has nonlinear viscoelastic behaviour (Kuo et al. 2011; Dong et al., 2003; Chapman, 1974). Further, preliminary characteristic tests showed that the Burger's model deformation under creep-recovery tests is similar to the woven wrinkle recovery deformation. Thus, the Burger's model is the more adequate model to describe the viscoelastic behaviour of fabric wrinkling. For the purpose of our study, we considered the nonlinear Burger's model to describe the viscoelastic behaviour of the fabric wrinkling.

Based on the Viscoelasticity Theory of textile materials, the Burger's model (figure 3), which consists of a Maxwell model associated in series with a Kelvin-Voigt model, is analysed in this paper. The four-element Burger model permitted us to study the viscoelastic behaviour of the wrinkle recovery. This model includes material elasticity represented by a spring (*$E_1$*) and material viscosity represented by a spring (*$E_2$*) and a dashpot (*$\eta_2$*) connected in parallel arrangement and material plasticity represented by a dashpot (*$\eta_1$*).

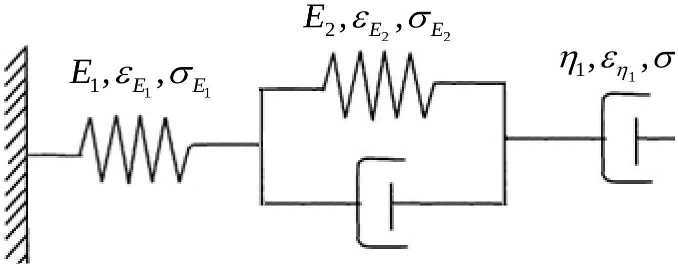


Figure 3: Burger's model.

The association of the springs and the dashpots in the Burger's model permitted to consider the following equations:

$$\sigma = \sigma_{E_1} = \sigma_{\eta_1} = \sigma_{E_2} + \sigma_{\eta_2} \quad (2)$$

$$\varepsilon = \varepsilon_{E_1} + \varepsilon_{E_2} + \varepsilon_{\eta_1} \quad (3)$$

Where $\sigma$ is the stress and $\varepsilon$ is the strain

$$\varepsilon_{E_1} = \frac{\sigma}{E_1} \quad (4)$$

$$\varepsilon_{E_2} = \frac{\sigma_{E2}}{E_2} = \frac{\sigma - \sigma_{\eta_2}}{E_2} \quad (5)$$

$$\frac{\partial \varepsilon_{\eta_1}}{\partial t} = \frac{\sigma}{\eta_1} \quad (6)$$

According to Equations (2)–(6), we get:

$$\frac{\partial \varepsilon}{\partial t} = \frac{1}{E_1}\frac{\partial \sigma}{\partial t} + \frac{1}{\eta_1}\sigma + \frac{1}{E_2}\frac{\partial \sigma}{\partial t} - \frac{\eta_2}{E_2}\frac{\partial^2 \varepsilon}{\partial t} + \frac{\eta_2}{E_1 E_2}\frac{\partial^2 \sigma}{\partial t} + \frac{\eta_2}{E_2 \eta_1}\frac{\partial \sigma}{\partial t} \quad (7)$$

Finally, the differential Equation (8) governs the stress–strain behaviour of the four-element Burger's model:

$$\frac{\partial^2 \varepsilon}{\partial t} + \frac{E_2}{\eta_2}\frac{\partial \varepsilon}{\partial t} = \frac{1}{E_1}\frac{\partial^2 \sigma}{\partial t} + \left(\frac{1}{\eta_1} + \frac{1}{\eta_2} + \frac{E_2}{E_1 \eta_2}\right)\frac{\partial \sigma}{\partial t} + \frac{E_2}{\eta_1 \eta_2}\sigma \quad (8)$$

In a creep test, the stress applied to material remains constant and the deformation changes during time. In order to describe the creep-recovery behaviour of the wrinkle recovery during relaxation using four-element burger's model, we expressed the deformation of wrinkle recovery as a function of the constant stress (the mass applied for wrinkling). The dependence of strain on time under the constant stress *$\sigma_0$* is given by Equation (9):

$$\varepsilon_{re}(t) = \frac{\sigma_0}{E_2}\left(1 - \exp(-\frac{E_2}{\eta_2}t_1)\right)\exp\left(-\frac{E_2}{\eta_2}t\right) + \frac{\sigma_0}{\eta_1}t_1 \quad (9)$$

Where:

- $\sigma_0$ is the constant stress.
- $\varepsilon_{re}$ is the recovery strain.
- $E_1$ and $E_2$ denote the Hookean elasticity of the springs numbers 1 and 2.
- $\eta_1$ and $\eta_2$ denote the Newtonian viscosity of the dashpots numbers 2 and 3.
- $t$ is the relaxation time during the wrinkle recovery.
- $t_1$ is the time of the application stress (1 min).

## 3. RESULTS AND DISCUSSIONS

In order to examine the proposed rheological model reliability during creep-recovery test, we studied the correlation between the experimental and theoretical creep-recovery curves and we determined the rheological model parameters from the experimental data.

To validate the Burger rheological model proposed to describe the viscoelastic behaviour of wrinkling after the stress removal, we studied the correlation between the experimental curves during the creep-recovery test, of different wrinkle characteristics obtained by applying the method of processing images (Zaouali et al., 2010), and the theoretical creep-recovery curves given by the creep-recovery equation of rheological model (Equation 9).

For this purpose, we compared experimental relaxation curves of wrinkle characteristics (wrinkle number, wrinkle surface roughness, wrinkle density, wrinkle length, and wrinkle height) with fitted curves of the Equation (9) by using "Origin 06" software. Figures 4-9 show the evolution of the wrinkling characteristics according to the relaxation time of two different fabrics, with different wrinkling appearance (cotton and polyester fabrics), having the following features:

Table 2: Characteristics of two different fabrics.

| Fabric Features | Cotton fabric | Polyester fabric |
|---|---|---|
| **Weave** | Plain | Twill |
| **Weight (g/m$^2$)** | 144 | 112 |
| **Thickness (mm)** | 0.23 | 0.14 |
| **Warp density (picks/cm)** | 32 | 38 |
| **Weft density (ends/cm)** | 22 | 28 |
| **subjective wrinkling grade** | **1** | **4** |

Figures 4, 5, 6, 7 and 8 show respectively the experimental and calculated relaxation curves for the wrinkle number "N", the wrinkle surface roughness "R", the wrinkle density "D", the wrinkle length "L" and the wrinkle height "H". Figure 9 shows the experimental and calculated creep-recovery curves for fabric wrinkling grade.

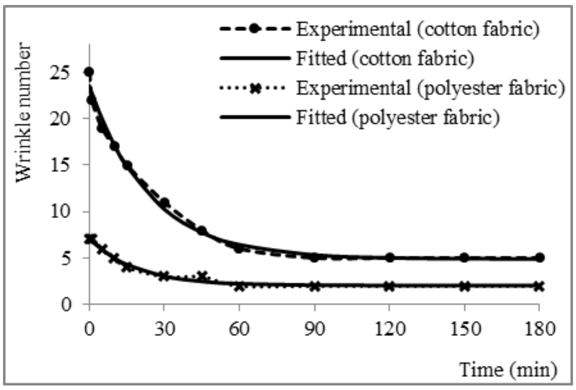


Figure 4: Experimental and fitted relaxation curves of wrinkle number.

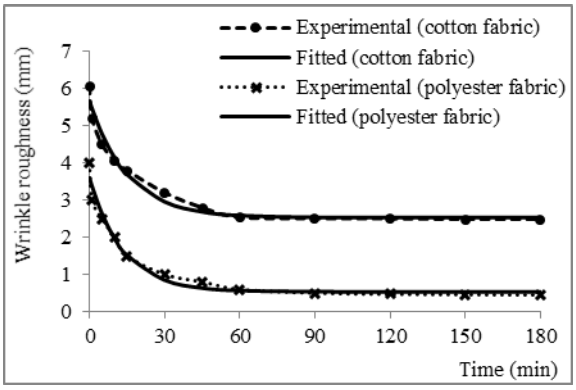


Figure 5: Experimental and fitted relaxation curves of wrinkle surface roughness.

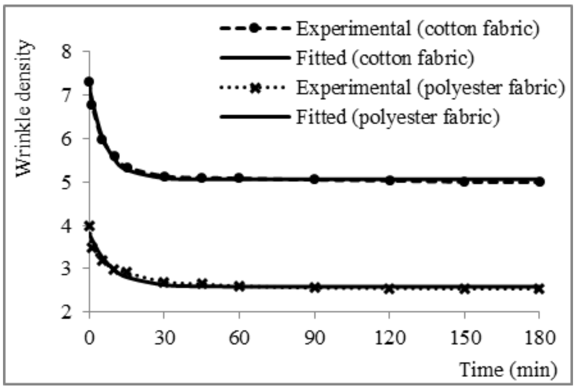


Figure 6: Experimental and fitted relaxation curves of wrinkle density.

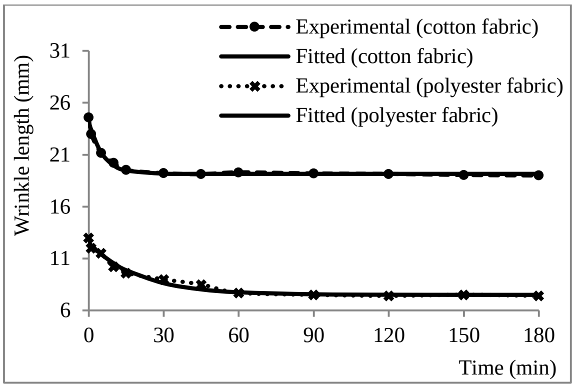


Figure 7: Experimental and fitted relaxation curves of wrinkle length.

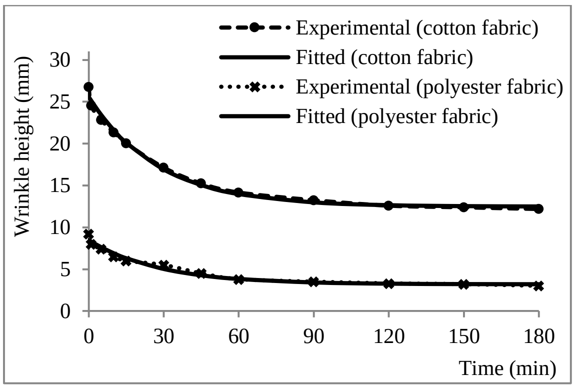


Figure 8: Experimental and fitted relaxation curves of wrinkle height.

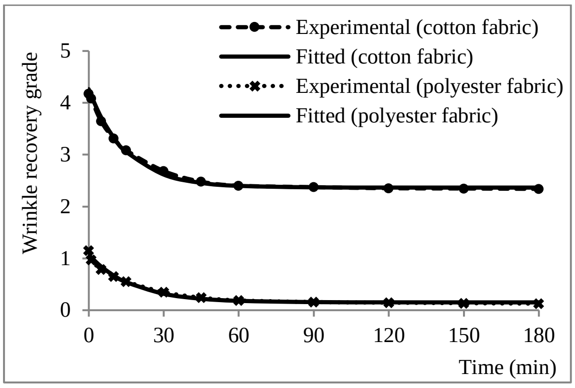


Figure 9: Experimental and fitted relaxation curves of fabric wrinkling grade.

Analysing Figures 4-9, it can be concluded that every experimental curve is similar to its corresponding theoretical creep-recovery curve given by the creep-recovery equation of Burger's model. Moreover, we observed a fast recovery of wrinkles between 0 and 60 min and a tendency to stabilize at higher relaxation times.

In order to study the reliability of the rheological Burger model, we determined rheological model parameters from experimental data and we studied the correlation between the experimental and theoretical creep-recovery curves. The calculated rheological parameters of cotton fabric related to creep-recovery test are summarised in Table 3.

Table 3: Burger model parameters of cotton fabric related to creep-recovery test.

| | *N* | *R* | *D* | *L* | *H* | *WR* |
|---|---|---|---|---|---|---|
| $E_1$ (N/mm) | 0.318 | 1.324 | 1.038 | 0.309 | 0.292 | 1.758 |
| $E_2$ (N/mm) | 0.016 | 0.150 | 0.484 | 0.241 | 0.019 | 0.251 |
| $\eta_1$ (N.s/mm) | 0.385 | 2.269 | 3.166 | 1.318 | 0.549 | 3.740 |
| $\eta_2$ (N.s/mm) | 1.508 | 2.905 | 1.450 | 0.383 | 0.589 | 3.108 |
| $R^2$ (%) | 99.2 | 97.5 | 99.2 | 98.9 | 99.1 | 99.5 |

The nonlinear Burger's model seems to be adequate to describe creep-recovery behaviour of wrinkle recovery. In fact, as shown in Table 3, the correlation coefficient $R^2$ exceeds 95% for all wrinkle characteristics (wrinkle number "N", wrinkle surface roughness "R", wrinkle density "D", wrinkle length "L", and wrinkle height "H"). Therefore, the correlation coefficient $R^2$ of fabric wrinkling grade also exceeds 95% and reaches 99%. Similar observations were noted for the other tested fabrics. The rheological parameters of the wrinkling grade, determined from the experimental data of the different used fabrics, are recapitulated in Table 4.

Table 4: Summary of rheological parameters of different tested fabrics.

| **Rheological parameters** | **Min** | **Max** | **Mean** | **CV (%)** |
|---|---|---|---|---|
| $E_1$ (N/mm) | 1.63 | 18.48 | 3.34 | 41.52 |
| $E_2$ (N/mm) | 0.214 | 0.54 | 0.312 | 30.05 |
| $\eta_1$ (N.s/mm) | 2.45 | 56.53 | 4.9 | 49.25 |
| $\eta_2$ (N.s/mm) | 2.545 | 8.122 | 3.826 | 36.37 |

Table 4 shows that the different tested fabrics with diverse characteristics, have different rheological parameters which are dispersed (important coefficient of variation showing the dispersion of data around the mean). Then we can deduce that the different rheological parameters depend on the characteristics of the fabrics.

Therefore, we note that the Burger's model seems to be the most appropriate to describe the actual recovery behaviour of wrinkling deformation generated by the method of "cylindre creux". Furthermore, the relaxation behaviour during wrinkling recovery is according to the creep-recovery equation.

Based on the Burger's model parameters in Table 3 and the creep-recovery Equation (9), the predicted values of wrinkling deformation can be calculated during relaxation. Thus, the wrinkle recovery behaviour can be predicted by the creep-recovery equation of Burger's model.

We also note that immediately after the stress removal, the specimen has a residual wrinkling deformation which tends to decrease over time (a phenomenon of recovery). In addition, the wrinkle recovery is not total even after an important relaxation time; this deformation is called permanent deformation. Indeed, after 3 hours of recovery the wrinkled fabric does not get its initial state. This reflects the imperfect elasticity textile fabrics.

According to literature (Ajiki et al., 2003; Dong et al., 2003; Mustalahti et al., 2010), Burger's model deformations during a creep-recovery test are characterized by an elastic deformation, viscoelastic deformation, and plastic deformation as shown in figure 10.

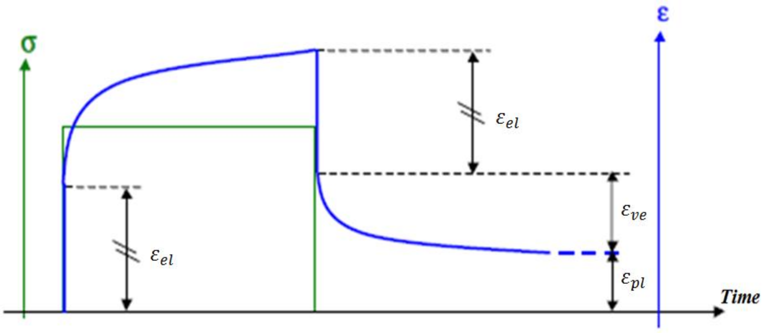


Figure 10: Burger's model deformations during a creep-recovery test.

Where

- $\varepsilon_{el}$ refers to the fast-elastic deformation caused by the spring $E_1$ ;
- $\varepsilon_{ve}$ refers to the viscoelastic deformation caused by the spring $E_2$ and the dashpot $\eta_2$ ;
- $\varepsilon_{pl}$ refers to the plastic deformation caused by the dashpot $\eta_1$.

Figure 10 shows the evolution of the fabric deformation during the creep-recovery behaviour of Burger's model. Therefore, in this paper, we can identify the components of deformation during a creep-recovery test of the different wrinkled fabrics. As a result, the proposed rheological model permitted also to determine and calculate the components of elastic, viscoelastic and plastic deformation for each wrinkled fabric. In fact, if a fabric was wrinkled, it would be deformed. Its deformation would have three formats: fast-elastic deformation, delayed deformation, and permanent deformation.

Based on the creep-recovery equation of Burger's model (Equation 9), the elastic deformation, the viscoelastic deformation and the plastic deformation are described respectively by Equations 10, 11 and 12.

$$\varepsilon_{el} = \frac{\sigma_0}{E_1} \tag{10}$$

$$\varepsilon_{ve} = \frac{\sigma_0}{E_2}\left(1 - exp\left(-\frac{E_2}{\eta_2} t_1\right)\right) \tag{11}$$

$$\varepsilon_{pl} = \frac{\sigma_0}{\eta_1} t_1 \tag{12}$$

Based on the rheological parameters of Burger's model of wrinkling deformation, and according to Equations 10, 11 and 12, the elastic deformation, viscoelastic deformation and the plastic deformation of all tested fabrics are calculated and their values are recapitulated in Table 5.

Table 5: Burger's model deformations of different tested fabrics.

| Deformation | Min | Max | Mean | CV (%) |
|---|---|---|---|---|
| $\varepsilon_{el}$ | 0.397 | 4.509 | 2.2 | 40.02 |
| $\varepsilon_{ve}$ | 0.875 | 2.769 | 1.844 | 34.22 |
| $\varepsilon_{pl}$ | 0.13 | 3 | 1.5 | 39.28 |

As shown in Table 5, the values of the elastic deformation, the viscoelastic deformation and the plastic deformation of different tested fabrics are dispersed. As a result, the different fabrics characteristics influence the deformation components during the wrinkling recovery.

The fast-elastic deformation and the delayed deformation are reversible, but the permanent deformation is irreversible. Indeed, when the weight is removed (removed stress), the fast-elastic deformation of the spring $E_1$ is recovered. Then, the delayed deformation caused by the spring $E_2$ and the dashpot $\eta_2$ decreases slowly. Moreover, because the dashpot $\eta_1$ causes plasticity deformation and opposes the deformation recovery, the fabric keeps a permanent deformation that can't be recovered. Experimentally, from 90 min of the wrinkling relaxation, the wrinkle recovery grade would be finally a constant.

According to Equation (12), the permanent deformation depends also on the application stress time $t_1$. Therefore, the more the time of application stress is important, the more the permanent deformation after the wrinkling recovery increases.

## 4. CONCLUSION

In this paper, we proposed a rheological model in order to study the recovery behaviour of textile fabric wrinkling. Then, we studied the correlation between the experimental curves during the creep-recovery test, of different wrinkle characteristics (wrinkle number, wrinkle surface roughness, wrinkle density, wrinkle length, wrinkle height, wrinkling grade), and the theoretical creep-recovery curves given by the creep-recovery equation of rheological model. As a result, the use of Burger's model was found to be successful for simulating the wrinkle recovery behaviour. Therefore, the actual recovery behaviour of multidirectional fabric's wrinkling generated by the French method "cylindre creux", can be predicted by the creep-recovery equation of Burger's model.

Furthermore, we note that immediately after the stress removal, the specimen has a residual wrinkling deformation which tends to decrease over time. In addition, the wrinkle recovery is not total even after an important time of relaxation. Indeed, after 3 hours of recovery the wrinkled fabric does not recover its initial state. This reflects the imperfect elasticity textile fabrics.

Based on the rheological model parameters determined from experimental data and the creep-recovery Equation, the predicted values of wrinkling deformation can be calculated during relaxation. This allowed us to calculate the components of elastic, viscoelastic and plastic deformation for each wrinkled fabric. Therefore, the fast-elastic deformation and the delayed deformation are reversible, but the permanent deformation is irreversible. Besides, the more the time of application stress is important, the more the permanent deformation after the wrinkling recovery increases.

## REFERENCES

**Ajiki, I., Postle, R. (2003).** Viscoelastic properties of threads before and after sewing. *International Journal of Clothing Science and Technology,* 15, 1, (January 2003), 12, 16-27, 0955-6222.

**Al-Gaadi, B., Göktepe, F., Halász, M. (2012).** A new method in fabric drape measurement and analysis of the drape formation process. *Textile Research Journal,* 82, 5, (March 2012), 11, 502-512, 0040-5175.

**Asayesh, A., Jeddi, A. A. A. (2010).** Modeling the Creep Behavior of Plain Woven Fabrics Constructed from Textured Polyester Yarn. *Textile Research Journal,* 80, 7, (May 2010), 9, 642-650, 0040-5175.

**Asvadi, S., Postle, R. (1994).** An analysis of fabric large strain shear behavior using linear viscoelasticity theory. *Textile Research Journal*, 64, 4, (April 1994), 7, 208-214, 0040-5175.

**Chapman, B. M. (1974).** A model for the crease recovery of fabrics. *Textile Research Journal,* 44, 7, (July 1974), 8, 531-538, 0040-5175.

**Dong, X., Zhang, J., Zhang, Y., Yao, M. (2003).** A study on the relaxation behavior of fabric's crease recovery angle. *International Journal of Clothing Science and Technology*, 15, 1, (January 2003), 9, 47-55, 0955-6222.

**Fridrichova, L., Zelova, K. (2011).** Objective evaluation of multidirectional fabric creasing. *Journal of the Textile Institute,* 102, 8, (August 2011), 7, 719-725, 0040-5000.

**Hezavehi, E., Shaikhzadeh Najar, S., Zolgharnein, P. (2010).** Wrinkle force and wrinkle recovery of worsted fabrics: A novel approach. *Journal of Textile Science and Technology,* 5, 2, (Spring and Summer 2010), 13, 25-37, 1735-8345.

**Jeddi, A. A. A., Shams, S., Nosraty H., Sarsharzadeh, A. (2003).** Relations between Fabric Structure and Friction: Part I: Woven Fabrics. *Journal of the Textile Institute,* 94, 3-4, (January 2003), 12, 223-234, 0040-5000.

**Kuo, C. J., Lin, W., Su, T. (2011).** Design and verification of fabric surface softness testing system. *Textile Research Journal,* 81, 16, (October 2011), 8, 1724-1732, 0040-5175.

**Mihailović, T. V., Nikolić, M. D., Simović, L. M. (1995)**. Resistance to creasing of clothing wool fabrics. *International Journal of Clothing Science and Technology*, 7, 4, (April 1995), 8, 9-16, 0955-6222.

**Mustalahti, M., Rosti, J., Koivisto, J., Alava, M. J. (2010).** Relaxation of creep strain in paper. *Journal of Statistical Mechanics: Theory and Experiment,* 2010, 7, (July 2010), 7, P07019-P07019, 1742-5468.

**NF G 07-125 (1974).** Essais des Etoffes, Détermination de l'Auto-Défroissabilité (Méthode au Cylindre Creux). In : *Norme française NF G 07-125, AFNOR.*

**ISO 139/A1 (2011).** Textiles - Atmosphères normales de conditionnement et d'essai. In : *Norme française,* N° Ref. 75994, N° d'édition. Ed 01/09/2011, 1-10.

**Shi, F., Hu, J. (2000).** Modeling the creasing properties of woven fabrics. *Textile Research Journal*, 70, 3, (March 2000), 9, 247-255, 0040-5175.

**Shi, F., Wang, Y. (2009).** Modelling crease recovery behaviour of woven fabrics. *Journal of the Textile Institute,* 100, 3, (April 2009), 5, 218-222, 0040-5000.

**Terzopoulos, D., Fleischer, K. (1988).** Modeling inelastic deformation: Viscoelasticity, plasticity, fracture. ACM SIGGRAPH *Computer Graphics*, 22, 4, (August 1988), 10, 269-278, 0097-8930.

**Vangheluwe, L., Kiekens, P. (1996).** Modelling relaxation behaviour of yarns, Part I: Extended, nonlinear behaviour model. *Journal of the Textile Institute*, 87, 2, Part I, (February 1996), 9,296-304, 0040-5000.

**Vangheluwe, L., Kiekens, P. (1997).** Simulation of procedures to avoid set marks in weaving caused by relaxation. *Textile Research Journal*, 67, 1, (January 1997), 6, 34-39, 0040-5175.

**Zaouali, R., Msahli, S., Sakli, F. (2007).** Parameters influencing fabrics wrinkling. *The Indian Textile Journal,* 117, 11, (August 2007), 5, 27-31, 0019-6436.

**Zaouali, R., Msahli, S., Sakli, F. (2010).** Fabric wrinkling evaluation: a method developed using digital image analysis. *Journal of the Textile Institute,* 101, 12, (December 2010), 11, 1057-1067, 0040-5000.