Theoretical Model for Predicting Creep Behavior of Plain Woven Fabrics

A. Asayesh[i], Ali A.A. Jeddi[ii]

ABSTRACT

A viscoelastic model has been developed to predict the creep behavior of plain woven fabrics using the yarn creep data and the structural parameters of the fabric. The model has been used to obtain theoretical creep data for fabrics with different weft densities and these data have been compared with experimental creep data. It has been observed that by increasing the weft density the fabric's creep decreases.

KEYWORDS

Creep, viscoelastic, woven fabric, weft density, fabric structural parameter.

1. INTRODUCTION

When stress is applied constantly, there is an increased extension with time in viscoelastic materials. This phenomenon is called creep. Almost all textile materials exhibit an appreciable amount of creep. The material and structure of the textiles as well as the amount of load and environmental condition affect on the creep behavior of textile materials [1-3]. Creep behavior of fibers and yarns is important in the yarn and fabric production processes. Many experimental and theoretical works [1-5] have been reported on the creep performance of fibers and yarns, but only a few discuss fabrics. Owing to the ever-growing uses of textile fabrics in technical applications, a study of fabric creep characteristics is necessary.

Nachane and Hussain [3] studied creep and inverse creep in nylon 6 monofilament, polyester multifilament yarn and wool and cotton spun yarns. They observed that the extent of creep and inverse creep differs from material to material and depends on the initial stress. It is also shown that cotton exhibits minimum inverse creep while nylon shows maximum inverse creep. However, wool and polyester have intermediate inverse creep values.

Gupta [4] reviewed various approaches for the enhancement of creep resistance of polypropylene products prepared from fibers, filaments, tapes and films for use as technical textiles. These include the right choice of starting material; appropriate processing parameters; cross linking; copolymerization; use of additives; and use of polymer mixtures. Also, he applied a model evolved for the long-range prediction of creep, to the creep of oriented yarn prepared from a polypropylene blend containing 5 wt. % of polyester. A nonlinear viscoelastic model was presented by Gupta and Kumar [5] to represent the creep behavior of nylon 6 filament. They observed that the presented model is able to predict the creep and creep-rate curves reasonably well.

The creep behavior of nonwoven and woven fabrics was investigated both theoretically and experimentally by Cui and Wang [6]. They modified the well-known Schapery nonlinear constitutive relation to make it suitable for characterizing the creep behavior of these fabrics. The modified constitutive equation demonstrates that total creep recovery strain can be divided into four parts, i.e., instantaneous elastic, instantaneous plastic, viscoelastic, and viscoplastic. Kothari and Patel [7] developed a model to predict the creep behavior of nonwoven fabrics using the fiber creep data and the structural parameters of the fabric. A network structure of the constituent fibers of nonwoven fabric was considered and creep strain was estimated for constant stress creep condition. The model was used to obtain theoretical creep curves for different nonwoven fabrics and these curves were compared with experimental creep curves. Results showed that a reasonable prediction can be made regarding the creep behavior of these fabrics based on the theoretical model.

Urbelis et al. [8-9] investigated creep and creep recovery of binary textile compound systems of textile fabrics assembled or fused together for garment manufacturing, under different constant loads. The total elongation was assumed to be comprised of elastic, viscoelastic, instantaneous irreversible and progressively developing irreversible (plastic) components. Referring to this mechanical model, which included generalized Voigt

---

[i] A. Asayesh, Department of Textile Engineering, Amirkabir University of Technology, Tehran 15914, Iran. (Email: a_asayesh@aut.ac.ir).

[ii] Ali A.A. Jeddi, Department of Textile Engineering, Amirkabir University of Technology, Tehran 15914, Iran. **Corresponding author** (Email: ajeddi@aut.ac.ir).

elements possessing regular discrete retardation time spectra was proposed for theoretical analysis of the processes. They observed that with the increase of the total load on the fused fabric systems the values of total, fast developing and creep elongations of the textile fabrics and the systems made up of them increase as well. Also, they found that the single component of the system undergoes very different partial tensions: the higher tension falls on the component possessing the higher modulus.

The aim of this study is to predict the creep behavior of plain woven fabrics by a mechanical model using the yarn creep data and the structural parameters of the fabric.

2. THEORETICAL BACKGRUND

When a textile material is subjected to stress or strain, two basic phenomena, i.e., creep and stress relaxation occur. Creep is extension with time under an applied load. If a constant load is applied to a fiber for a given time, the instantaneous extension is followed by creep. The removal of the load gives rise to an instantaneous recovery, usually equal to the instantaneous extension, followed by a further partial recovery with time (primary creep), which still leaves some un-recovered extension (secondary creep) [1].

In order to model the creep behavior of a plain woven fabric under constant load, first we consider the creep behavior of a single yarn of the fabric. If a constant load F is applied to the yarn, then the total deformation of the yarn consists of two parts: the immediate reversible (elastic) deformation which is represented by Hookian spring, the elasticity constant of which is M and the delayed partially reversible (viscoelastic) deformation which is represented by Voigt model, and its elasticity and viscosity constants are, respectively E and η. Therefore, we suggest a typical mechanical model (Fig. 1) that describes the viscoelastic behavior of the yarn. Thus, the total elongation of the yarn ($e(t)$) under constant load F at each time can be calculated as following:

$$e(t) = \frac{F}{M} + \frac{F}{E}(1 - \exp(-t/\tau)) \qquad (1)$$

where $\tau = \eta/E$.

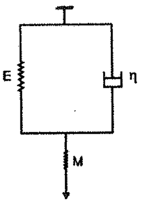

Figure 1: The proposed model for yarn.

For a woven fabric, we can consider a bundle of parallel yarns in warp or weft directions of fabric. Therefore, in each direction, there will be a combined model consists of n_1 or n_2 (the number of yarns in weft and warp direction, respectively) number of the mechanical model in parallel (Fig. 2). Also, we assume that warp or weft yarns move together in the load direction and there will be no slippage between warp or weft yarns. Thus, the elongation of the bundle of yarns ($e'(t)$) under constant load F in weft direction can be calculated as follows:

$$e'(t) = \frac{1}{n_1} e(t) \qquad (2)$$

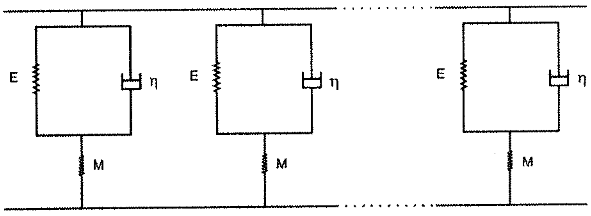

Figure 2: The generalized proposed model in parallel designed for fabric.

Then, considering the Pierce geometry for plain woven fabric [10] with following assumptions:

- The yarn is a cylindrical elastic rod
- Yarns are incompressible

we consider a unit cell of the fabric (a weft yarn which is crossed with two warp yarns at the right angle) subjected to constant load F in the weft direction (Fig. 3). This load consists of two components. The first component (f_v) decrimps the weft yarn wherein f_{v1} displaces the warp yarns vertically while f_{v2} displaces the warp yarns horizontally, and the second part (f_w) causes the yarn elongation or in other words the fabric elongation in weft direction. This component of load is calculated as follows:

$$f_w = F\cos\theta_1 \qquad (3)$$

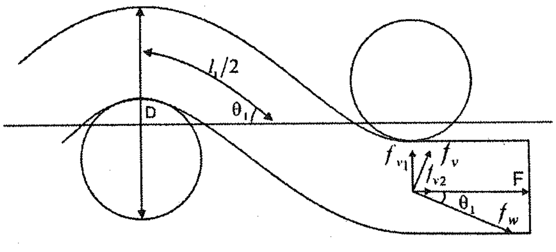

Figure 3: Peirce geometry for plain woven fabric.

By using Peirce geometry in warp jamming condition:

$$\theta_1 = \frac{l_1}{D} \qquad (4)$$

$$D = d_1 + d_2 \tag{5}$$

$$d_i = 2\sqrt{\frac{Tex_i}{\rho_{f_i} . \phi_i . \pi . 10^5}} \tag{6}$$

where θ_1 is weft weave angle (radian);

l_1 is weft yarn modular length (cm);

d_1, d_2 is weft and warp yarn diameter respectively (cm);

Tex is yarn linear density;

ρ_f is fiber density (g/cm^3);

ϕ is yarn packing density;

Elongation of the weft yarn under load f_w which consists of the immediate reversible (elastic) elongation and the delayed partially reversible (viscoelastic) elongation leads to fabric elongation in the weft direction. Elongation of the weft yarn followed by fabric elongation in the weft direction gradually decreases the weft weave angle (θ_1). We assume that variation of (θ_1) during creep test is negligible. Thus, the total elongation of the unit cell under constant load F at each time can be calculated as following:

$$e(t) = \frac{F\cos\theta_1}{M_1} + \frac{F\cos\theta_1}{E_1}(1 - \exp(-t/\tau_1)) \tag{7}$$

Therefore, the total elongation of the fabric under constant load F in the weft direction at each time can be calculated as below:

$$e'(t) = \frac{1}{n_1}\left[\frac{F\cos\theta_1}{M_1} + \frac{F\cos\theta_1}{E_1}(1 - \exp(-t/\tau_1))\right] \tag{8}$$

This equation shows the creep behavior of plain woven fabrics which is related to the yarn creep behavior and the structural parameters of the fabric.

3. EXPERIMENTAL

Five different plain woven fabrics varying in weft density were produced using 300 denier twisted textured polyester yarn as warp yarn and 150 denier intermingle textured polyester yarn as weft yarn. Fabrics characteristics are given in Table 1.

Creep behavior of fabrics was studied by using HCR 25-400 servo-hydraulic dynamic material testing device (Zwick/Roell, Germany) along the weft direction. The dimensions of each specimen were 5 × 1 cm, gauge length was 1.6 cm, and initial load was 1 N. The creep test was performed under 40 N load (36% of fabric breaking strength), and duration of creep test was 30 minutes. From each structure of fabric three specimens were tested and fabric extension measurements were recorded at time intervals of 0.215 s, and the average creep curves of the fabrics were plotted using Matlab software. The average creep of the fabrics at the end of test is shown in Table 1.

In order to estimate M_1, E_1 and τ_1 of weft yarn, the same apparatus of creep tester in a similar manner was used. The amount of constant load applied to the yarn was taken 1.8 N (30% of yarn breaking strength), and duration of creep test was 30 minutes. Five samples of yarn with 10 cm in length were tested and yarn extension measurements were recorded at similar time interval as stated in case of fabric test. The average creep curve of the yarn is shown in Fig. 4. By curve fitting the average experimental data to (1) using Matlab curve fitting tool, the values of M_1, E_1, τ_1 were estimated as following:

$M_1 = 0.214$ N/mm

$E_1 = 2.07$ N/mm

$\tau_1 = 200$ s

Table 1: Experimental and theoretical creep of the fabrics at the end of creep test for different fabric densities.

Sample ID	Warp Density (warps/cm)	Weft Density (wefts/cm)	Experimental Creep of Fabric (c_e) (mm)	Theoretical Creep of Fabric (c_t) (mm)	$\frac{c_t - c_e}{c_t}$ (%)
1	34	24	0.4650	0.4597	-1.15
2	34	25	0.4073	0.4397	7.37
3	34	26	0.3687	0.4214	12.51
4	34	28	0.3173	0.3889	18.41
5	34	29	0.3003	0.3746	19.83

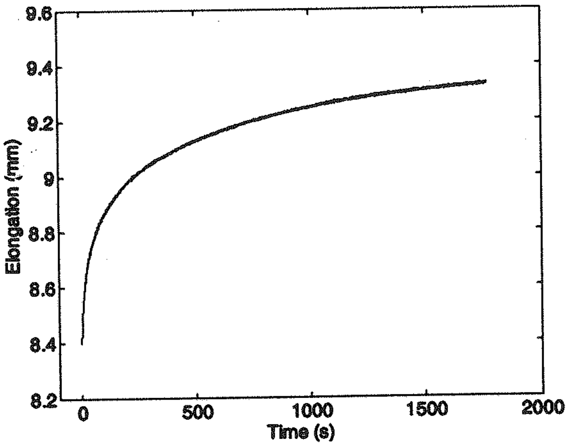

Figure 4: Average experimental creep curve of the yarn.

To measure the weft yarn modular length (l_1), 5 cm of fabric sample was unravelled. Then, this length of yarn was de-crimped using 56 grams weight. This experiment was performed for 10 samples and the average length of these samples was calculated and divided to warp density. The measured value was found $l_1 = 0.0356$ cm.

The weft weave angle (θ_1) can be calculated using equations (4-6) and by substituting $\phi = 0.75$ [11] and $\rho_f = 1.38$ g/cm^3. It is assumed that the packing density of textured yarn at the contact point in the fabric is the same as packing density of continuous filament yarn. The calculated weave angle was obtained $\theta_1 = 1.047$ radian.

Using (8), crep curves of the woven fabrics were obtained theoretically based on the yarn creep behavior and structural parameters of the woven fabric using the computer program developed for this purpose (Fig. 5). The theoretical creep of fabrics at the end of creep test was calculated and is shown in Table 1.

4. RESULTS AND DISCUSSION

The comparison of experimental and theoretical values of the fabrics creep at the end of creep test (30 minutes) indicates that the theoretical creep is higher than the experimental values for tighter fabrics. It can be attributed to the friction between yarns which was neglected. This difference is increased with increasing of weft density, but is less than 20%. Generally speaking, the percentage of difference between experimental and theoretical creep represents that the prediction of creep behavior of these fabrics using the presented theoretical model shows reasonable agreement with the experimental creep curves.

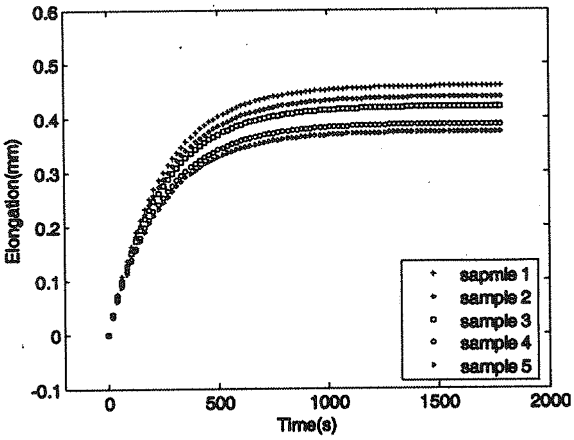

Figure 5: Theoretical creep curves of fabrics with different weft densities.

In order to explain the effect of weft density on the creep behavior of plain woven fabric in the weft direction, the average creep curve of fabrics with different weft densities have been shown graphically in Fig. 6. Creep curves illustrate that the fabrics deform initially giving high instantaneous elongation but thereafter show less creep. It is observed that an increase in weft density leads to a decrease in fabric creep in the weft direction. The reason for this is that with increasing weft density, the number of yarns in the fabric in the load direction increases, thus each yarn sustains less fraction of the total load. As a result, the elongation of the yarn and consequently fabric decreases.

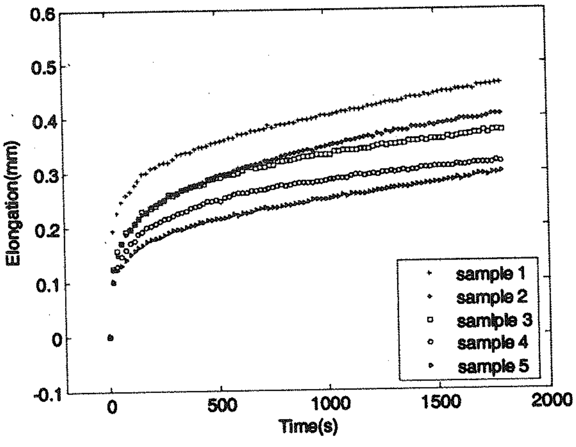

Figure 6: Experimental creep curves of fabrics with different weft densities.

5. CONCLUSION

A theoretical model for predicting the creep behavior of plain woven fabrics based on the creep behavior of constituent yarns and the structural parameters of the fabric has been proposed.

The effect of weft density on the creep behavior of fabrics in the weft direction has been investigated. As expected, an increase in weft density leads to a decrease in fabric creep.

Comparison has been made between experimental and theoretical values of the fabrics creep at the end of creep test. Experimental creep shows less than 20% deviation from theoretically predicted creep that is a reasonable prediction regarding the creep behavior of plain woven fabrics based on this theoretical model.

6. REFERENCES

[1] W. E. Morton and J. W. S. Hearl, *Physical Properties of Textile Fibers*, first ed., Manchester& London: Textile Institute, 1962, pp. 333-347.

[2] M. T. O'Shaughnessy, "An experimental study of the creep of rayon", *Text. Res. J.*, vol. 18, pp. 263-280, 1948.

[3] R. P. Nachane and G. F. S. Hussain, "Inverse creep in some textile yarns", *Indian Journal of Fiber& Textile Research*, vol. 23, pp. 81-84, 1998.

[4] V. B. Gupta, "Modification and long-range prediction of the creep behavior of polypropylene", *Indian Journal of Fiber& Textile Research*, vol. 22, pp. 236-245, 1997.

[5] V. B. Gupta and S. Kumar, "A model for nonlinear creep of textile fibers", *Text. Res. J.*, vol. 47, pp. 647-649, 1977.

[6] S. Z. Cui and S. Y. Wang, "Nonlinear creep characterization of textile fabrics", *Text. Res. J.*, vol. 69, pp. 931-934, 1999.

[7] V. K. Kothari and P. C. Patel, "Theoretical model for predicting creep behavior of nonwoven fabrics", *Indian Journal of Fiber& Textile Research*, vol. 26, pp. 273-279, 2001.

[8] V. Urbelis, A. Petrauskas, and A. Vitkauskas, "Creep and creep recovery behavior of textile fabrics and their fused systems", *Material Science*, vol. 11, pp. 162-168, 2005.

[9] V. Urbelis, A. Petrauskas, and A. Vitkauskas, "Time-dependent mechanical behavior of heterogeneous textile fabric systems", *Fibers & Textiles in Eastern Europe*, vol. 12, pp. 37-42, 2004.

[10] F. T. Pierce, "The geometry of cloth structure", *J. Text. Inst.*, vol. 28, pp. 45-96, 1937.

[11] J.W. S. Hearle, P. Grosberg, and S. Backer, *Structural Mechanics of Fibers, Yarns, and Fabrics*, New York: Wiley, 1969, p. 97.