CREEP BEHAVIOUR OF KEVLAR 49
INOKUCHI MATHEMATIC ANALYSE

S. KACI[1], Z. TOUTOU[1], P. MORLIER[2]

[1]*Institut de Génie-Civil,*
Université Mouloud MAMMERI de Tizi-Ouzou
Tizi-Ouzou, 15000, Algérie
[2]*Laboratoire de Rhéologie du Bois de Bordeaux*
33610 Cestas-Gazinet, Pierroton, INRA, France

ABSTRACT :

Composite materials which are highly used in high technology industries such as aeronautic and space are nowadays introduced in building industry.
Because of their good physicochemical characteristics, composite cables can be used as substitute for steel in prestressed concrete. However, their long term mechanical behaviour is still not fully understood. Therefore, a rheological model describing the creep behaviour of cords of Kevlar type 49 is presented in this study.
The obtained simulations are in good agreement with the experimental results.

KEYWORDS : Kevlar, Prestress, Creep, Mechanical Behaviour, Viscoelasticity, Rheological Model, Simulation, Building Industry.

INTRODUCTION

Composite cables, because of the fact that they are not subject to corrosion and, in addition, in the long run and at room temperature, show prestress losses due to weak flow and relaxation, can be used as prestress tools. Also their low density as well as their highly performing tension features incite researchers and industry related people to use them to build bridges and other structures, as well as for restoration purposes in damaged structures. Indeed, these composite materials are being used in many industries such as aeronautics and car manufacturing, and they are the subject of many research works (1,2, 3, 4, 5). However, to use these Kevlar reinforced cables as means of prestress, it is necessary to get a good knowledge tendon (6, 7, 8, 9), helped to know the evolution with time of its relaxation modulud.
Within the scope of this article, the results of the research which has been carried out on the study of the creep behaviour under tension of composite cables (Kevlar high modulus, 0.95 TWA2) are presented.

INOKUCHI MATHEMATIC ANALYSE (Application to creep behaviour of Kevlar 49)

The material tested is a braided high modulus Kevlar cord, impregnated with a heat-hardening resin of Polyester urethane; The composite, thus obtained, has a cylindrical shape of diameter 0.95 mm (11).

Using existing experimental results obtained on this cords of Kevlar type 0.95 TWA2 (12,13), a rheological model, based on the method of Inocuchi (14), for the long term behaviour of this material is presented.
The general model which correspond to a creep function of a viscoelastic material is made of an association in series of a Maxwell cells and a certain number of Kelvin Voigt solids depending on the viscoelasticity degree of the material.
The total strain is the sum of the elementary strains. Therefore, the general expression of the creep function is given by:

$$f(t) = J_0 + \frac{t}{\eta_0} + \sum_{i=1}^{n} J_i(1 - e^{-t/\theta_i}) \tag{1}$$

Now, the problem consists in obtaining the different parameters (η_0 , J_0, J_i, η_i and θ_i).

DETERMINATION OF THE PARAMETERS (J_0 , η_0 , J_i, η_i and θ_i).

Determination of J_o and η_0

The creep experimental curve of the viscoelastic material is represented on figure 1.

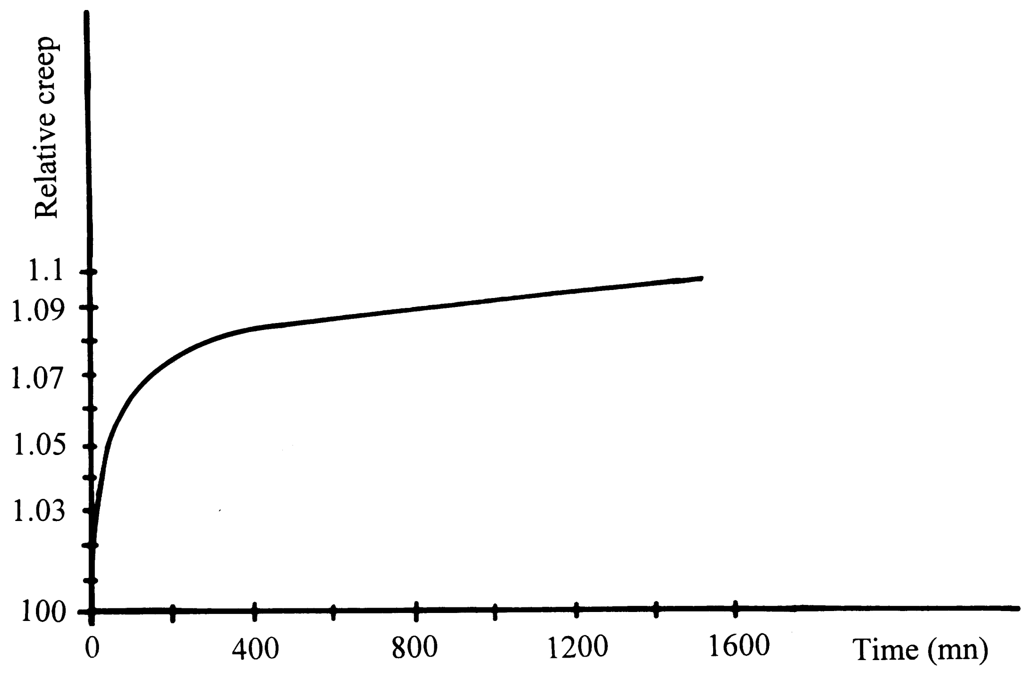

Figure 1. Experimental creep behaviour of Kevlar 49 (12)

From this curve, the value of J_o and η_o can be obtained because:

J_o (which is the instantaneous elastic compliance) represents the ordinate at the origin of the curve f(t).

$\frac{1}{\eta_0}$ (which is the coefficient of Newtonian viscosity) represents the slope of the asymptotic the curve.

J_o and η_o are respectively measured as:

$J_o = 1.02*10^{-11}\ Pa^{-1}$
$\theta_0 = 10^5$ mn
And η_o =9800 GPa.mn ≈ ∞ (considered as infinite).

Next, there is still to determine the number n_i of the Kelvin Voigt cells and, therefore, the parameters η_i and J_i corresponding to each cell.

Determination of the parameters J_i, η_i, and θ_i

The parameters are determined by means of the mathematical analysis developed by Inocushi (14).

Determination of the parameters J_1, η_1 and θ_1

Given a function such that:

$$Q(t) = \sum_{i=1}^{n} J_i e^{-t/\theta_i} \tag{2}$$

Considering that t is sufficiently big, it is clear from a first analysis that the function to be considered is:

$$Q(t) = J_1 e^{-t/\theta 1} \Rightarrow LnQ(t) = LnJ_1 - t/\theta_1 \quad .(3)$$

It follows that the graph of LnQ(t) = f(t) is a non linear curve, figure 2.

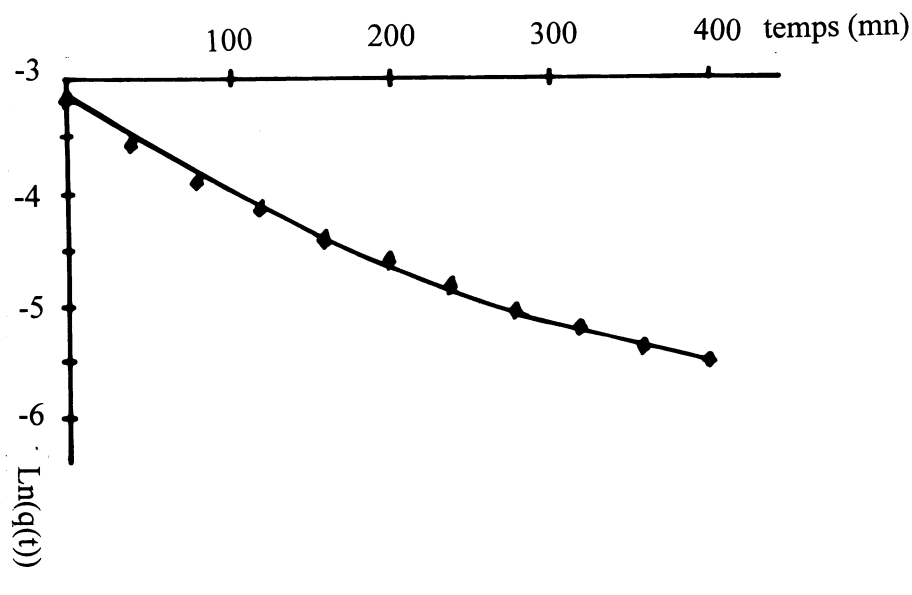

Figure2. Representative curve of the function Ln Q(t)

From this figure, it can seen that $Ln(J_1)$ is the ordinate at the origin. Therefore, the values of the parameters J_1 and η_1 can be obtained as :

$J_1 = 1.23 * 10^{-11} Pa^{-1}$, $\theta_1 = 400$ mn and $\eta_1 = 32.5$ GPa.mn.

Determination of the parameters J_2, η_2 and θ_2

As a second analysis, the function $Q'(t)= q(t)- J_1e^{-t/\theta 1}$ is considered. Taking the natural logarithm, it follows:

$$LnQ'(t)=Ln(q(t)- J_1e^{-t/\theta 1}) \qquad (4)$$

From the graph Ln(Q'(t)), figure 3, the values of the parameters J_2, θ_2 and η_2 are obtained.

$J_2= 3.02 * 10^{-11}\ Pa^{-1}$, $\theta_2 = 80$ mn and $\eta_2= 2.649$ GPa.mn.

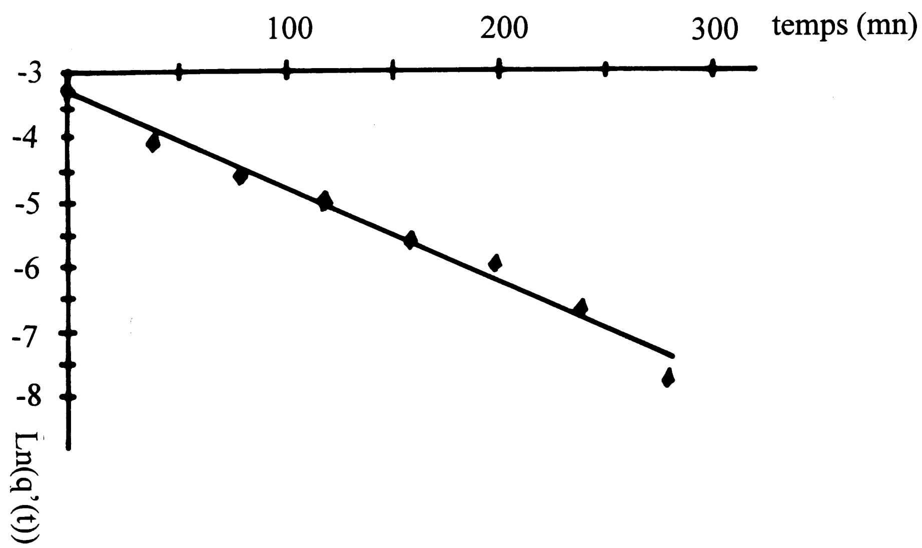

Figure 3. Representative curve of the function Ln Q'(t)

Since the graph of Ln(Q'(t)) is a linear curve, there is no need to do a third analysis. Therefore, the material Kevlar 49 can be represented adequately with two Kelvin Voigt solids.

CONCLUSION

The long term behaviour of Kevlar 49 can be represented by a model composed of a spring (compliance Jo) and two Kelvin Voigt cells (figure 4). The creep function can expressed as follows:

$$f(t) = (1.02 + 1.23(1 - e^{-t/400}) + 3.02(1 - e^{-t/80})) * 10^{-11} \qquad (5)$$

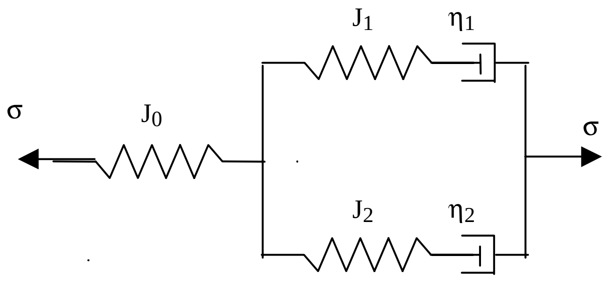

Figure 4. Rheological model of Kevlar 49 cable (type 0.95 TWA2)

The obtained results are in good agreement with experimental ones as shown on figure 5.

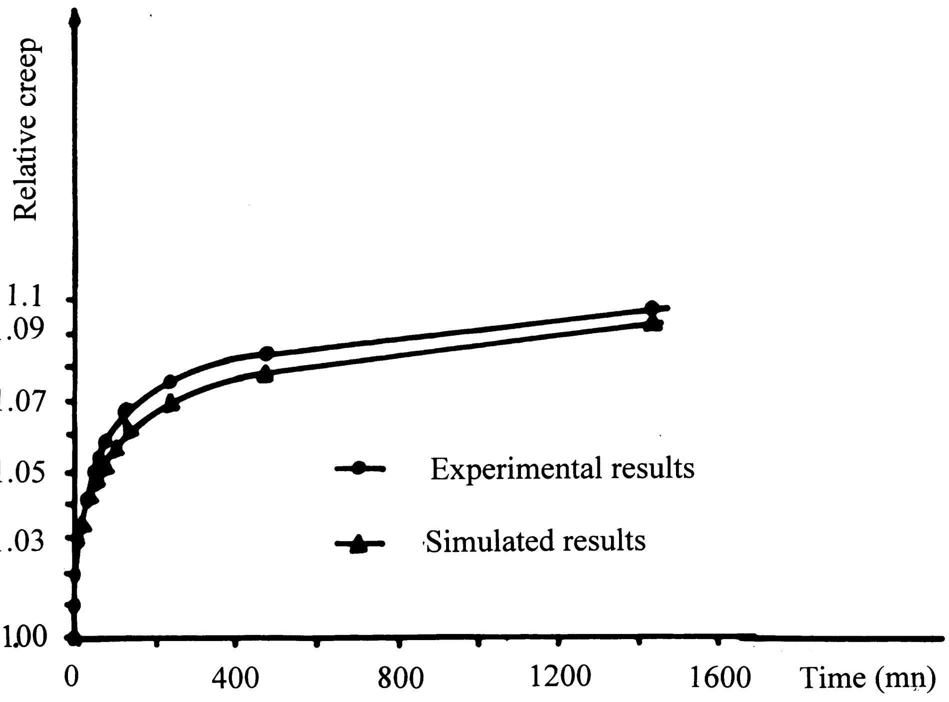

Figure 5. Creep behaviour of Kevlar 49 cable (type 0.95 TWA2)

SYMBOLS

- f : creep function of the viscoelastic material
- t : time
- J_o : instantaneous elastic compliance
- η_o : coefficient of newtonian viscosity
- $\theta_0 = J_o * \eta_o$: retardation time
- J_1, η_1, θ_1, : parameters of the Kelvin Voigt cell number 1
- J_2, η_2, θ_2, : parameters of the Kelvin Voigt cell number 2

REFERENCES

1. Brandt J., Drechsler K., Richter H., The use of high-performance thermoplastic composites for structural aerospace applications. Status and outlook, Proceeding of Ninth International Conference on Composite Materials, vol. VI, pp 143-150, Ed. A. Miravete, University of Zaragoza, (Spain) 1993.
2. Iyer S. L., Khubchandani A., Evaluation of graphite composite cables for prestressing concrete, Proceeding of Première Conférence Internationale sur les Matériaux Composites d'Avant-garde pour Ponts et Charpentes (MCAPC/1), pp 73-82, Ed. K.W. Neal et P. Labossière, Société Canadienne de Génie-Civil, Sherbrooke, (Canada) 1992.
3. Nath R.B., Fenner D.N., Galiottis C., Progression of interfacial failure in Kevlar49 and carbon fibre composites: elasto-plastic finite element analysis, Proceeding of Seventh European Conference on Composite Materials, Vol.1, pp 27-32, Ed. The Institute of Materials, (London) 1996.
4. Mc Kay K.S., Erki A.-H., Aramid tendons in pretensioned concrete applications, Proceeding Première Conférence Internationale sur les Matériaux Composites d'Avant-garde pour Ponts et Charpentes, pp 221-230, Ed. K.W. Neal et P. Labossière, Société Canadienne de Génie-Civil, Sherbrooke, (Canada) 1992.
5. Reed P. E., Warnet L. L., Damage development in impacted composite pipes, Proceeding of Third International Conference on Deformation and Fracture of Composite, pp 345-351, Ed. The Institute of Materials, (Guilford, UK) 1995.
6. Kaci S., Câbles composites pour la précontrainte: Etude de la relaxation, Première Conférence Internationale sur les Matériaux Composites d'Avant Garde pour Ponts et Charpentes, pp 89-100, , Ed. K.W. Neal et P. Labossière, Société Canadienne de Génie-Civil, Sherbrooke, (Canada) 1992.
7. Kaci. S., Experimental study of mechanical behavior of composite cables for prestress, A.S.C.E, journal of engineering mechanics, vol. 121, NO. 6, pp 709-716, June 1995.
8. Kaci S., Khennane. A., Temperature effect on the relaxation modulus of composite cables for prestress, Proceeding of Seventh European Conference on Composite Materials, Vol. 1, pp 159-166, Ed. The Institute of the Materials, (London, U.K), 1996.
9. Kaci. S., Toutou. Z., Modélisation du comportement viscoélastique des câbles composites pour la précontrainte, Deuxième Conférence Internationale sur les Matériaux Composites d'Avant-garde pour Ponts et Charpentes, pp 335-340, Ed. M. El-Badry, Société Canadienne de génie civil, (Canada), Aout 1996.
10. Kaci. S., Study of dynamic behavior of tension of prestressed composite cables (temperature-related), Proceeding of Ninth International conference of Composite Materials, Ed. A. Miravete, University of Zaragoza,. Vol. III, pp 293-300, (Madrid) 1993.
11. Kaci. S., Toutou. Z., Study of the viscoelastic functions of composite cables for prestress, Proceeding of Fifth International Conference on Automated Composites, pp 435-442, Ed. The Institute of Materials, (Glasgow, U.K), September 1997.
12. Kaci. S., Khennane. A., Study of the creep behavior of composite cables for prestress, Proceeding of Third International Conference on Deformation and Fracture of Composite, University of Surrey, Ed. The Institute of Material, pp 644-652, (Guilford, U.K) 1995.
13. Kaci. S., Khennane. A., Temperature effect on the creep and dynamic behaviors of K evlar prestressing cables, Canadian Journal of Civil Engineering, Vol. 24, N° 3, Juin 1997.
14. Couarraze G., Grossiord J.L., Analyse Mathématique d'Inokuchi, in Initiation à la rhéologie, 2nd edition, Lavoisier Tec & Doc, June 1991.