

## Experimental and modelling study of effect of surface treatment on the creep condition of flax fiber reinforced composites

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**Abstract.** This article was focusing for experimental and mathematical modelling study the creep condition of FFRP (Flax Fiber Reinforced Polymer) under hygrothermal aging condition. In last time FRPs have been adopted as alternatives to traditional structural materials for industrial application due to their high tensile strength, high stiffness to weight ratio and better fatigue resistance. The recent developments of FRPs are towards the growth and usage natural FRP (Fiber Reinforced Polymer) in the field of engineering. FFRP is one of the most commonly used natural FRP. FFRP has the advantages of lightweight, low cost and easy recyclability. In this paper The unidirectional flax fabric was comparison with sample unidirectional flax fabric with chemical treatments of flax fiber are adopted by alkalization. The alkalization group is soaked in 5 wt% NaOH solution for 0.5 h at 25°C. The samples were experimental tested for creep in several days. Results of creep and elastic parameters were different.

### Introduction

In present time are researches and developments of FRPs are for growth and use of natural FRP in the field of mechanical engineering, especially for the transport industry [1-2]. FFRP is the most commonly used natural FRP bridge. FFRP has advantages of lightweight, low cost and easy recyclability. However, due to the short history of FFRP in engineering field, the durability and long-term performance of FFRP remains an open question. Therefore we were focusing for experimental and mathematical modelling study the creep condition of FFRP (Flax Fiber Reinforced Polymer) under hygrothermal aging condition.

### Experimental study of creep condition

We were using the unidirectional flax fabric which is on the (Fig. 1). We were testing of chemical treatments of flax fiber by alkalization. The alkalization group is soaked in 5 wt% NaOH solution for 0.5 h at 25°C [3]. After the treatment, the flax fabric is washed by distilled water and dried in an oven. The treated flax fabric was used to manufacture FFRP. Epoxy resin were used as the matrix. The FFRP specimen is made of approximately 30% fiber in volume. The dimension of FFRP specimen in rectangular form is 50mm x 10mm x 1.35mm. The creep tests scheme is shown in Table 1. Creep tests were carried out with DMS (Dynamic Mechanical Spectrometer) 6100 (Fig. 2), at a three-point bending mode, with a constant stress level of 20 MPa for a specific time period of 30 min. All experimental values were obtained by an average value of three specimens.



Fig. 1: A sample of unidirectional flax fabric

Table 1: Creep condition test

Surface treatment	Hygrothermal aging time/days				
	0	1	4	9	16
Untreated	U-0	U-1	U-4	U-9	U-16
Alkalization	Al-0	Al-1	Al-4	Al-9	Al-16

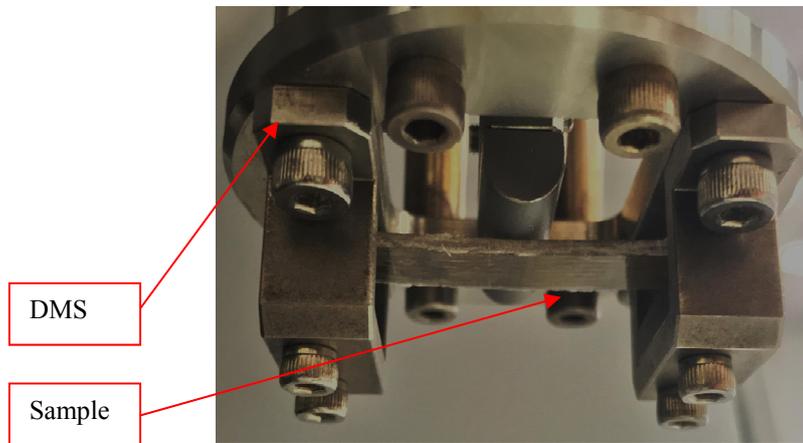


Fig. 2: Experimental testing of three-point bending mode

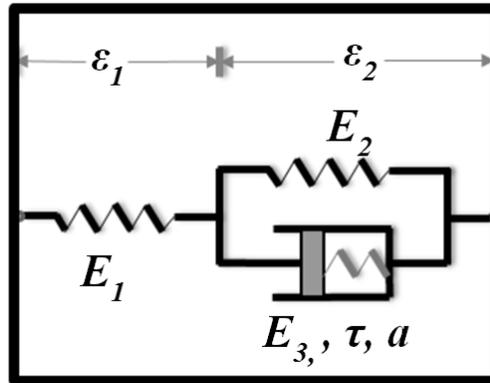


Fig. 3: Reologic model of five-parameter FPT

### Mathematical study of creep condition

For mathematical study of creep condition we can use traditional reologic models such as Maxwell model (consists of springs and dashpots connected in series) and Kelvin model (consists of springs and dashpots connected in parallel). For better results instantaneous deformation and stress, we were using a combination of Poynting-Thomson form [4] is adopted in this paper. Fig. 3 shows a five-parameter FPT (Fractional derivative Poynting-Thomson) model, which consists of springs and fractional derivative spring-pot. The constitutive relation of FPT model can be described as follows (1).

$$\sigma + A\tau^\alpha D^\alpha \sigma = B\varepsilon + C\tau^\alpha D^\alpha \varepsilon, \quad (1)$$

Where  $A = E_3 / (E_1 + E_2)$ ,  $B = E_1 E_2 / (E_1 + E_2)$ ,  $C = E_1 E_3 / (E_1 + E_2)$ . By using Laplace transform technique, the creep compliance  $J(t)$  of FPT model can be obtained (2).

$$J(t) = \frac{1}{B} + \frac{AB - C}{BC} E_{\alpha,1} \left[ -\frac{B}{C} \left( \frac{t}{\tau} \right)^\alpha \right], \quad (2)$$

Where Mittag-Leffler function [5] is defined as:  $E_{\alpha,\beta}(z) = \sum_{k=0}^{\infty} \frac{z^k}{\Gamma(\alpha k + \beta)}$ , ( $\alpha, \beta > 0$ ). For simplification of the parameters of the parallel parts in the FPT model,  $E_2$  and  $E_3$  are postulated as the same:  $E_3 = E_2 = E^*$ . The simplified expression of creep compliance is (3).

$$J(t) = \frac{1}{E_1} + \frac{1}{E^*} \left[ 1 - E_{\alpha,1} \left( -\left( \frac{t}{\tau} \right)^\alpha \right) \right], \quad (3)$$

The material parameters  $E_1$ ,  $E^*$ ,  $\tau$ ,  $\alpha$  can be obtained by fitting the experimental data as

(4).

$$\min f(\mathbf{x}) = \sum_{i=1}^m [J(\mathbf{x}, t_i) - r_i]^2, \quad (4)$$

$$s.t. \begin{cases} x_i \geq 0, i = 1, \dots, c-1 \\ 0 \leq x_c \leq 1 \end{cases}$$

Where  $J(\mathbf{x}, t_i)$  and  $r_i$  is the calculated and test result of creep compliance at time  $t_i$ , respectively.  $\mathbf{x} = (x_1, \dots, x_c)^T$  is the column vector of material parameters.  $c$  is the number of parameters. The parameter represents the order of fractional calculus is set as  $x_c$ .  $m$  is the number of test points, and  $m > c$  is required. If the final optimization value of  $x_c$  is 1, it indicates that the Newton dashpot is better than the fractional derivative spring-pot, and vice versa.

## Results and discussion

The results obtained from the creep test of FFRP are shown in Fig. 4. The creep compliance increases with the hygrothermal ageing time. Under the same hygrothermal ageing time, the chemically treated specimens demonstrate lower creep compliance, which indicates the improvement in creep property of FFRP caused by surface treated. For example, after 16 days of ageing, compared to the untreated group, the creep compliance of alkalization group at the end of the test decreased by 31.54% respectively.

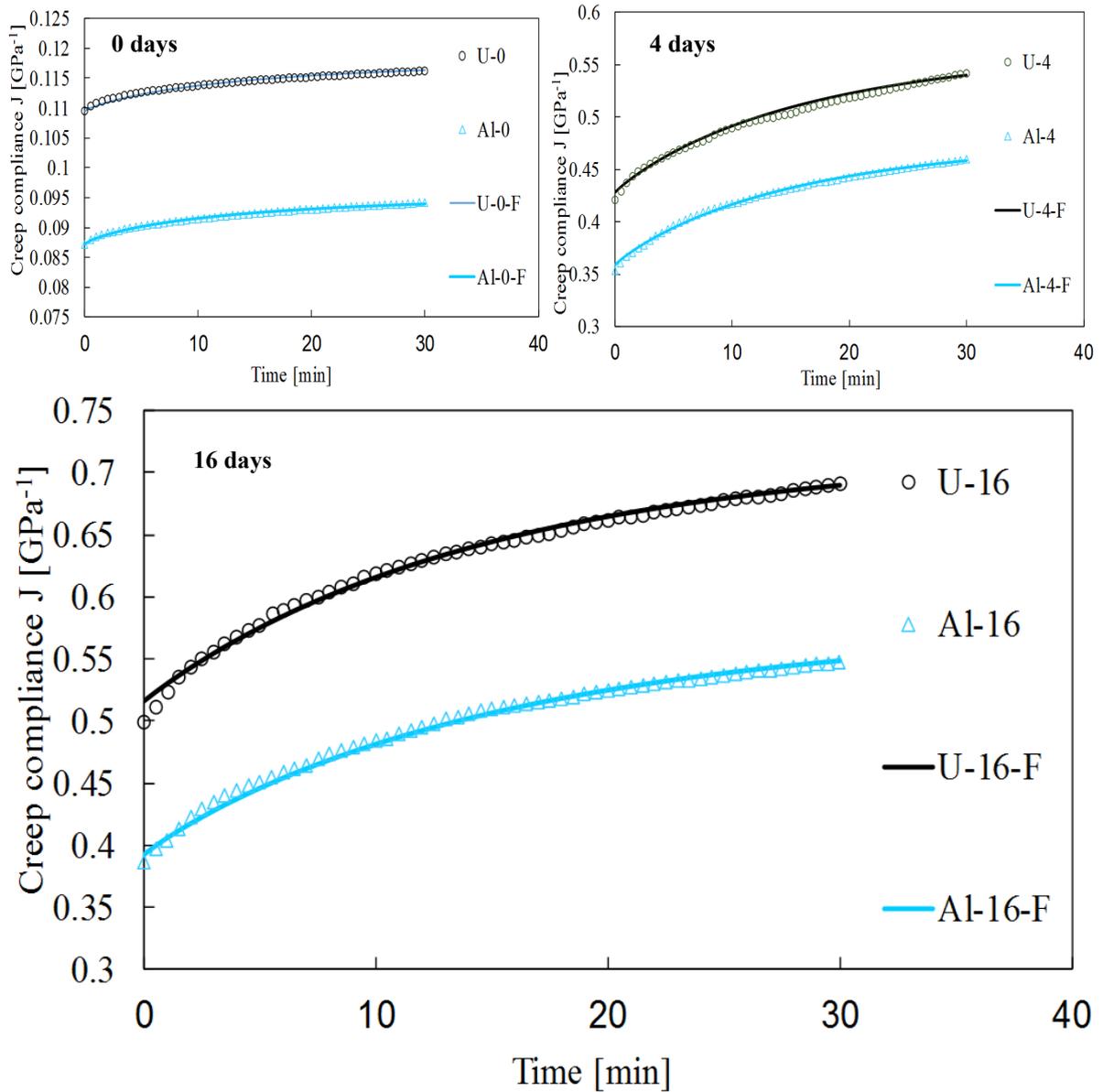


Fig. 4: Results of creep condition of FFRP from experiment and FPT model

Table 1: Parameters of FPT model

Surface treatment	Parameters	Hygrothermal aging time/days				
		0	1	4	9	16
Untreated	$E_1$	9.133	2.571	2.336	2.225	1.936
	$E^*$	109.189	8.412	6.953	6.168	4.916
	$\tau$	17.571	17.824	18.129	17.555	15.034
	$\alpha$	0.820	0.892	0.920	0.959	0.977
Alkalization	$E_1$	11.464	3.009	2.786	2.569	2.547
	$E^*$	110.882	8.292	7.981	8.184	5.178
	$\tau$	17.048	16.748	16.953	17.713	16.783
	$\alpha$	0.786	0.875	0.915	0.927	0.940

The curve-fitting results provided by FPT model presented in **Chyba! Nenalezen zdroj odkazů.** show a fair agreement with test results for both untreated and treated specimens. The influence of hygrothermal ageing time on FPT model parameters is depicted in Table 2. The

elastic modulus of the Hook spring in series part  $E_1$  determines the initial strain of FPT model:  $\varepsilon_0 = \sigma / E_1$ . The value of  $E_1$  decrease after exposure to hygrothermal ageing condition, resulting in increase of  $\varepsilon_0$  after 1 day, 4 days, 9 days and 16 days of ageing, respectively. For example, after hygrothermal ageing of 16 days was alkalization group decreased approximately 24%. As demonstrated in Tab.2, hygrothermal ageing does not have a noticeable effect on  $\tau$ . The value of  $\alpha$  increase with hygrothermal ageing time. E.g. after 1 day, 4 days, 9 days and 16 days of ageing,  $\alpha$  of untreated group is increased aproximetly 9%, 12%, 17%, 19%, respectively. According to the definition of fractional derivative, the close of  $\alpha$  to 1, the nearer the material to the ideal fluid. The trend of  $\alpha$  indicates that more viscous character after the hygrothermal aging.

## Conclusions

This article was focusing for experimental and modelling study the creep condition of FFRP under hygrothermal aging condition. Comparisons to experimental data reveal that the proposed mathematical FPT model works effectively. The results show that the creep compliance of FFRP significantly decrease with the surface treatment, this is attributed to the enhancement of fiber/matrix interface. In addition, although the modified fractional creep model is established for the FFRP in this paper, this model may have potential applications in creep analysis of other natural fiber reinforced composite materials.

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