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Experimental Analysis of Degradation of Bending Properties of Composite Materials After Accelerating Aging

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Abstract. Eco-friendly fiber reinforced polymer (FRP) has gained much attention recently because of its low density, low cost and abundant resources. Flax FRP (FFRP) is a commonly used eco-friendly FRP in various fields, such as automobile, packaging, and building construction. In this paper was prepared experimental analysis of degradation of bending properties of FFRP after accelerating aging. Accelerated aging tests are useful to predict the performance of FFRP only if such tests can be shown to correlate with natural aging. The experimental study carried out in this paper aimed at developing a better understanding of the effect of accelerated aging on the mechanical behavior of FFRP. The flexural strength and flexural modulus of FFRP decrease significantly with aging time.

Introduction

In recent years, the use of flax fiber as a potential alternative to traditional fiber such as glass fiber and carbon fiber in FRP has gained attention among researchers [1-4, 10-11]. Compared to glass fiber and carbon fiber, flax fiber presents low density, low cost and easy recyclability. However, the porous structure of flax fiber leads to high water absorbability [5]. The interaction between hydrophilic fiber and hydrophobic matrix results in weakening of fiber/matrix interface, dimensional instability, matrix cracking and degradation of mechanical properties of the FFRP [6]. Some experimental studies have been done to study the effect of humidity and temperature on mechanical behavior of FFRP. The weakening of matrix-fiber interface is the main damage mechanism caused by water aging of the FFRP. In [7] found that the residual tensile strength of FFRP subjected to salt solution is higher than GFRP. Also authors reported that after 38 days of hygrothermal aging with a relative humidity of 90%, the elastic modulus and tensile strength of FFRP decrease by 58% and 52% [8].

Approach of study of bending properties of samples after accelerating aging

The FFRP specimen is made of approximately 30% fiber in volume. The dimension of FFRP specimen in rectangular form is 50mm×10mm×1.35mm. Accelerated aging tests are useful to predict the performance of FFRP only if such tests can be shown to correlate with natural aging. In 2018 was carried out natural aging test in Nanjing (China) [5]. Results of bending properties of FFRP after natural aging are show in Fig.1. And the decreasing rate of the flexural properties slows down with the increase of aging time. Compared with reference group, the flexural strength decreases by 11.17%, 14.89%, 15.49%, and the flexural modulus decreases by 21.33%, 32.28%, 35.77% after experimental days.

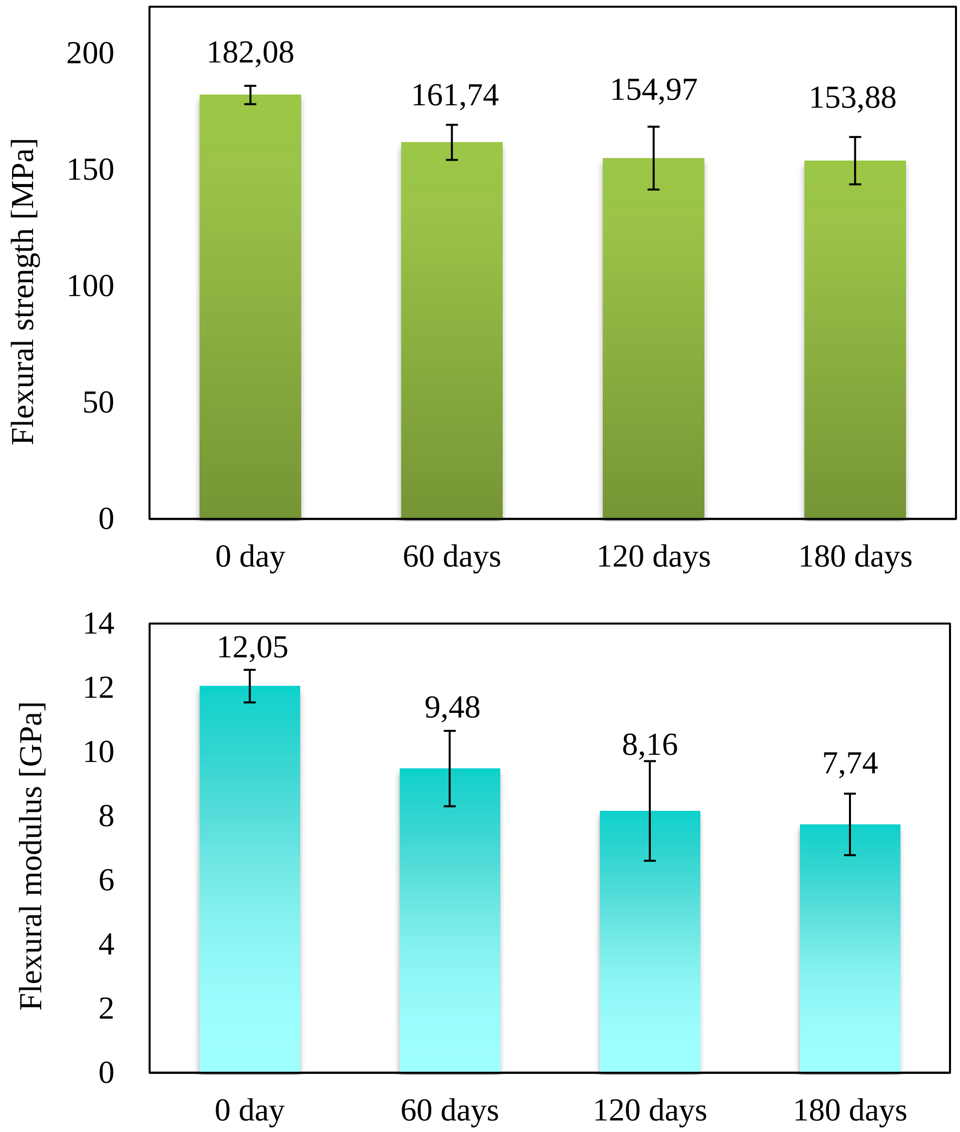

Fig. 1: Bending properties of FFRP after natural aging: (above) Flexural strength, (below) Flexural modulus

Therefore, it is important to find the conversion relationship between accelerated aging and natural aging. According to equation as described in [5] is the acceleration factor k_t can be obtained as (1).

$$k_t = \frac{t_1}{t_2} = \frac{e^{-C/(T_2\phi_2)}}{e^{-C/(T_1\phi_1)}}, \quad (1)$$

where t_1 is the natural aging time, t_2 is the accelerated aging time, T_1 and ϕ_1 are the temperature and relative humidity under natural aging conditions, T_2 and ϕ_2 are the temperature and relative humidity under accelerated aging environment, C is experimental coefficient.

Another method of accelerated moisture absorbed estimation mentioned in [9] is given by equation (2).

$$1/k_t = \frac{t_2}{t_1} = \frac{D_1}{D_2}, D = D_0 \exp(-C/T) \tag{2}$$

In this mathematical equation, the quotient of two diffusion coefficients is taken as the acceleration coefficient. Where D_0 and C is the diffusion-related constants at room temperature.

Experimental analysis of bending properties of samples after accelerating aging

The specimens were periodically taken out and tested under three-point loading to assess the flexural properties (Fig. 2). All experimental values were obtained by an average value of five specimens. The loading rate was 2 mm/min. Load and deflection were recorded by the test device.

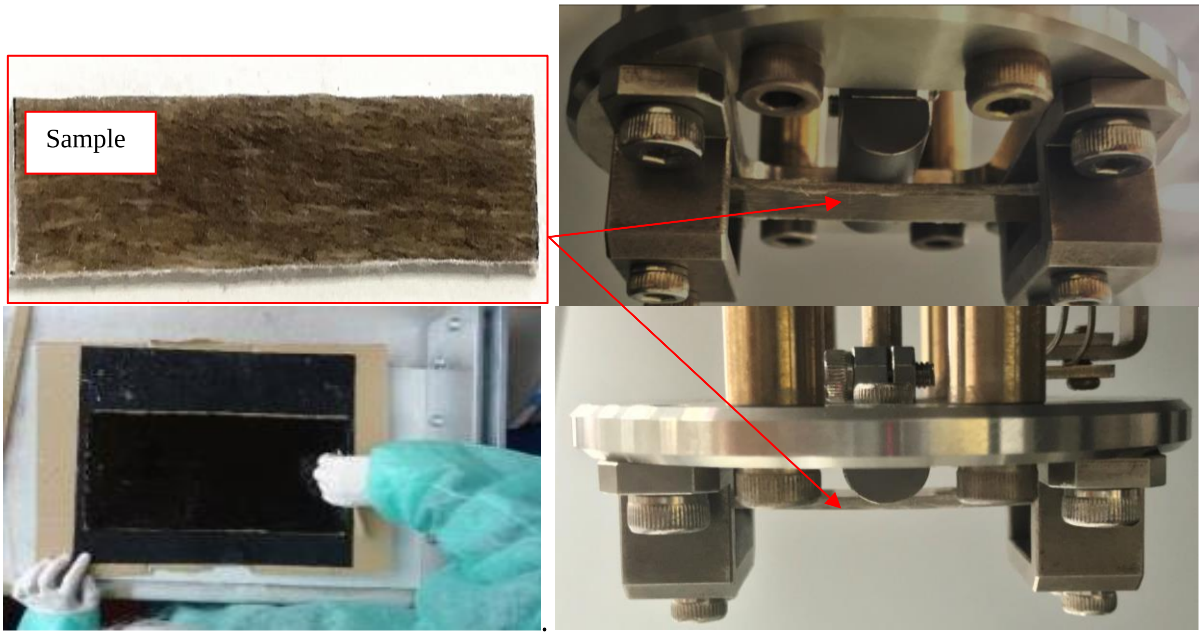

Fig. 2: Preparing of sample 50mm×10mm×1.35mm (left), device for experiment (right)

Results and discussion

To determine the correlation of accelerated aging test to natural aging test, the daily temperature and humidity during natural aging test were recorded. Corresponding accelerated aging time is calculated according to acceleration factor k_t in Eq. (1). Results are in Tab.1. According to Eq. (1), the accelerated aging time corresponding to each natural aging period can be obtained as $t_2 = \frac{t_1}{k_t}$. Where t_2 is the accelerated aging time, t_1 is the natural aging time. The accelerated aging time corresponding to 60 days, 120 days, and 180 days of natural aging is 1.08 h, 37.2 h, and 167.8 h is in Fig.3. Accelerated aging tests were carried out according to the calculated time. For example, the bending strength of FFRP under accelerated aging is 20.28%, 16.71%, and 13.51% higher than the natural aging. It mainly because only two factors (temperature and humidity) are considered in the accelerated test, and the specimens will be affected not only by temperature and humidity, but also by light, rainwater, chemical erosion, et al. The bending modulus of specimens under accelerated aging corresponding to 180 days of natural aging is lower, this phenomenon may be caused by higher water uptake.

As shown in **Chyba! Nenalezen zdroj odkazů.**, the color of the specimens has changed obviously after aging. And with the increase of aging time, the boundary between matrix and fiber is more and more obvious. The comparison between the flexural strength and flexural modulus of FFRP under natural aging and corresponding accelerated aging is show in Fig. 1. The results show that the flexural strength and flexural modulus under both aging conditions decrease with time. The flexural strength obtained from the corresponding accelerated aging is slightly larger than those obtained from the natural aging test.

Tab. 1: Results of k_t factor

Period	1	3	5	6	7	8	9
k_t	5.60×10^{76}	2.51×10^{5}	2.18×10^{3}	2.49×10^{2}	3.90×10^{2}	3.26×10^{2}	39.70
Period	10	12		15		18	
k_t	58.57	40.68		13.7658		35.098	

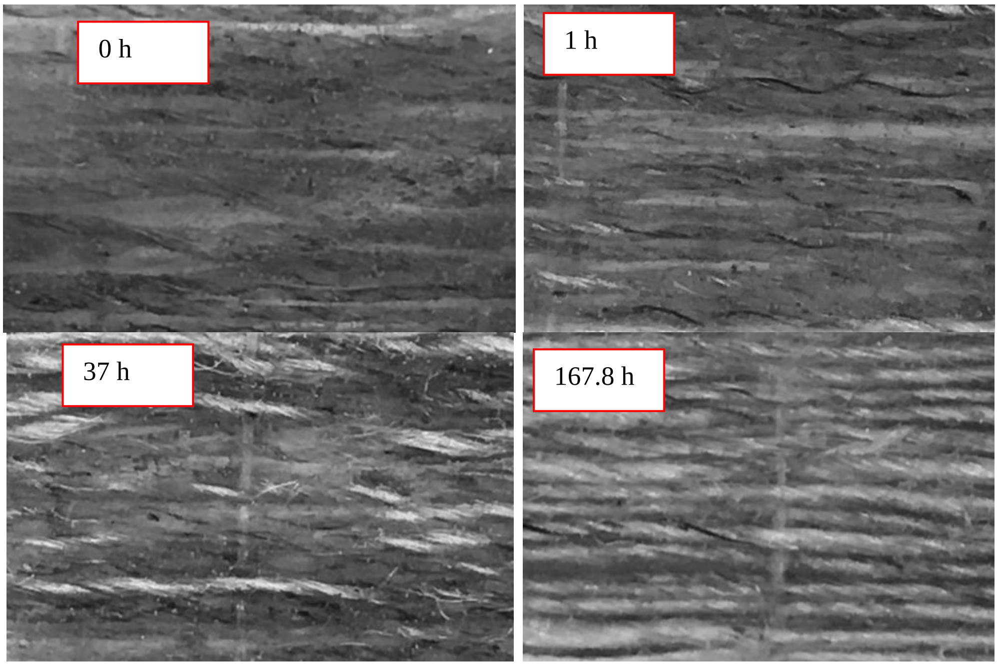

Fig. 3: Damage of sample of FFRP under accelerated aging

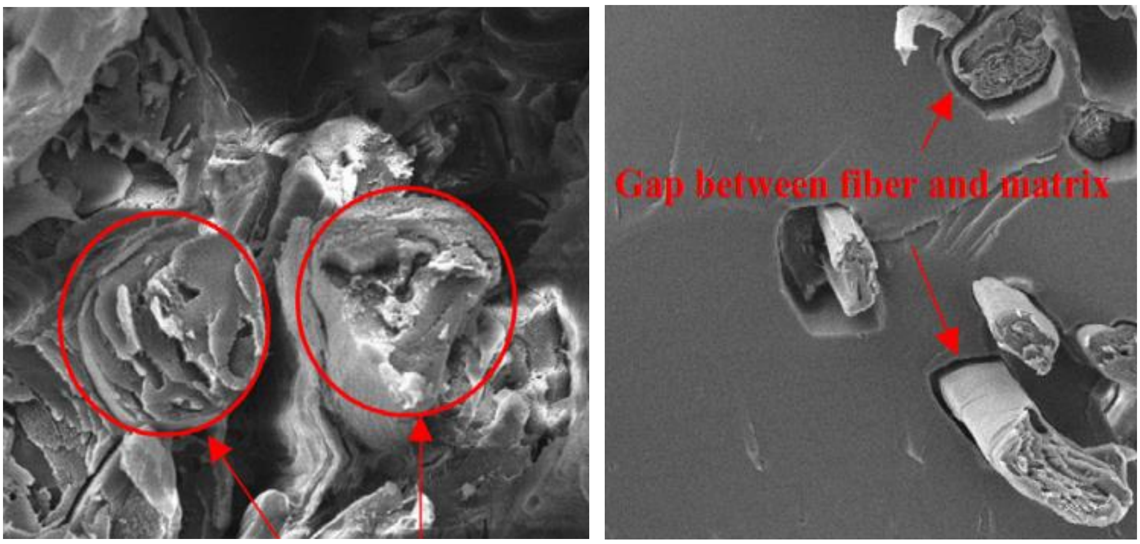

Fig. 4: Detail of morphology structure of FFRP sample: before under accelerated aging (left), after 167.8 hour under accelerated aging (right)

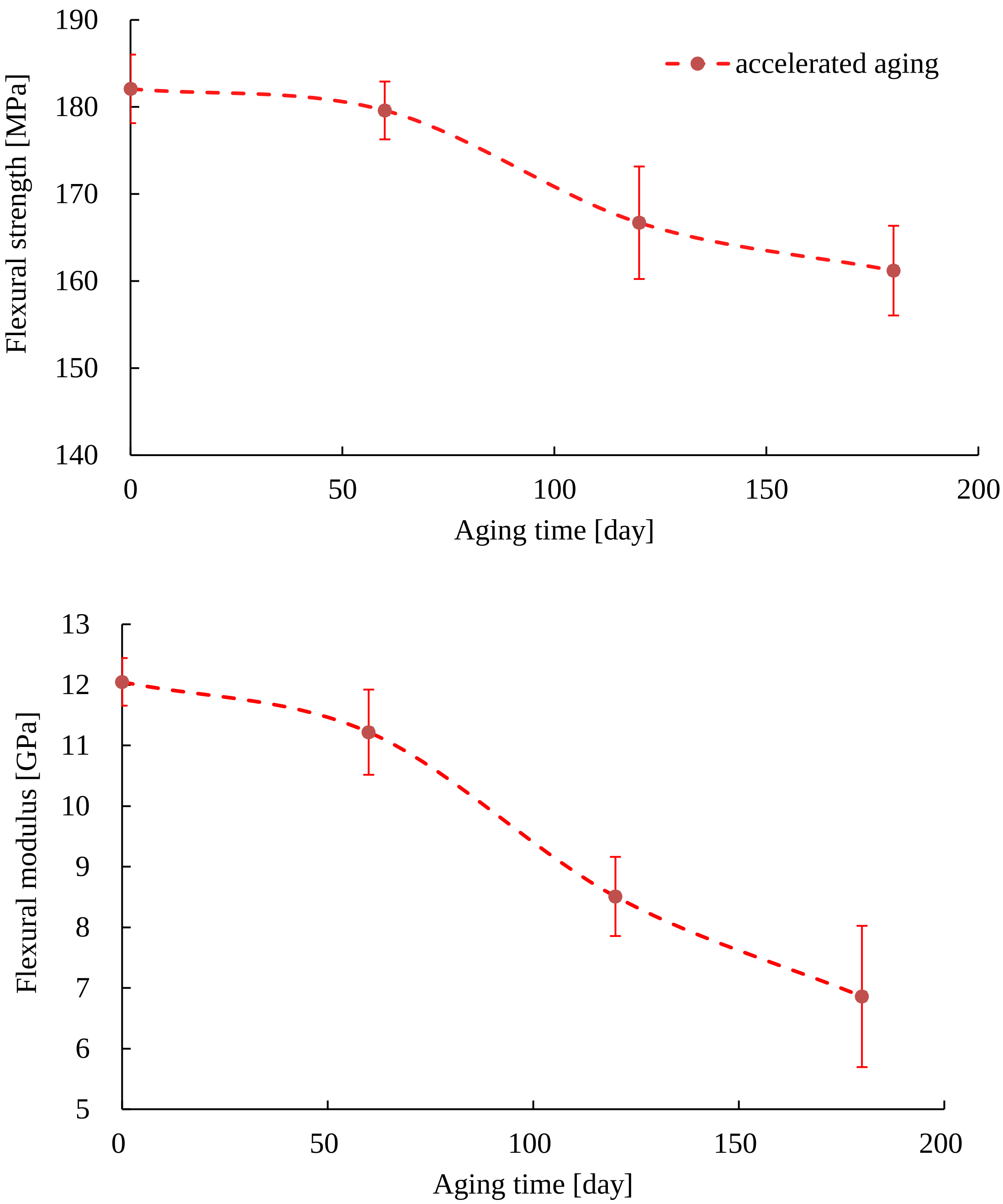

Fig. 1 Results of bending properties of FFRP under accelerated aging: (above) flexural strength, (below) flexural modulus

Conclusions

This article focused on an experimental and model-based study aimed at developing a better understanding of the effect of natural ageing and accelerated ageing on the mechanical behaviour of a flax fibre reinforced composite. The bending force and the FFRP bending module decreases significantly with age. The decreasing rate of bending properties slows with increasing age. The accuracy of the model results was verified by comparing the results of the rapid ageing and natural ageing test.

The results of the model may have applications in the durability analysis of other composite materials reinforced with natural fibres, and influencing factors such as ultraviolet light, chemical erosion, stress and so on may be introduced by adjusting parameters.

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