Composites: Part A 87 (2016) 153–160

Contents lists available at ScienceDirect

Composites: Part A

journal homepage: www.elsevier.com/locate/compositesa

Hybridisation effect on diffusion kinetic and tensile mechanical behaviour of epoxy based flax–glass composites

El Hadi Saidane *, Daniel Scida, Mustapha Assarar, Hamid Sabhi, Rezak Ayad

University of Reims Champagne-Ardenne, Laboratory of Engineering and Material Sciences (LISM, EA4695), IUT de Troyes, 9 rue de Québec, CS 90396, 10026 Troyes Cedex, France

ARTICLE INFO

Article history:
Received 4 December 2015
Received in revised form 21 April 2016
Accepted 23 April 2016
Available online 23 April 2016

Keywords:
A. Natural fibre composites
A. Hybrid
B. Mechanical properties
Diffusion kinetic

ABSTRACT

This paper aims at investigating the hybridisation effect on the diffusion kinetic and the tensile mechanical behaviour of flax–glass fibres reinforced epoxy composites. For this purpose, hybrid composites composed of flax and glass fibre laminates with different stacking sequences were consolidated by compression moulding and subjected to environment ageing. The obtained results show that the water uptake and the diffusion coefficient are clearly reduced by the addition of glass fibre layers in flax laminate. The ageing conditions performed show that the flax–glass hybridisation presents a positive effect in a wet environment at low temperatures (~20 °C) in the Young's modulus and the tensile strength. For example, the Young's modulus fell by 50% and 41% for hybrid laminates with 6% and 11% of glass fibres, and by 67% for the Flax laminate. However, the flax–glass hybridisation was not necessarily a relevant choice when the hybrid laminates were exposed in a wet environment at high temperatures. Indeed, at 55 °C, this hybridisation had a negative effect on the tensile strength and on the specific tensile strength.

1. Introduction

In recent years, composite materials reinforced with natural fibres such as flax, hemp, sisal and jute have been considered by several studies as being a potential alternative to glass fibres reinforced polymer composites [1–6]. In addition to their high environmental friendliness, natural fibres present good specific mechanical properties, easy incineration at the end of the life cycle, low cost and low energy consumption [7–10]. In spite of these advantages of natural fibres, many obstacles can restrain their use as reinforcement in different applications. In fact, their inherent susceptibility to moisture expansion in humid atmosphere and when immersed in water, makes them poor resistant to moisture absorption. Compared to the traditional composites, it was reported by several authors that the effect of moisture absorption leads to a degradation of the mechanical performance of natural fibre reinforced composites [11–17].

With the aim of improving the mechanical properties as well as the moisture resistance behaviour of natural fibre reinforced composites, some recent studies have suggested a combination of vegetable and synthetic fibres in the same matrix to produce hybrid composites [18,19]. Furthermore, the hybridisation of natural fibres with synthetic ones can also reduce the environmental impact and the material cost. Consequently, many researchers have studied the hybrid composites on various aspects [20–26]. For example, Ramesh et al. [20] evaluated the mechanical properties of sisal-jute-glass fibres reinforced polyester hybrid composites. They indicated that the addition of sisal and jute fibres in glass fibre composites improved the mechanical properties of hybrid composites. Sabeel Ahmed and Vijayarangan [21] studied the effect of glass fibre hybridisation and stacking sequences on tensile, flexural and interlaminar shear properties of woven jute-glass fibres reinforced hybrid composites. The authors observed that the incorporation of glass layers above and below of jute fibre reinforced laminate enhanced some properties of hybrid composites. They also observed that stacking sequences affected significantly the flexural and interlaminar shear strength. Recently, Zhang et al. [22] investigated the hybridisation effects of composites made by unidirectional flax fibres and different glass fibres content. The influence of hybrid ratio and stacking sequence between flax and glass fibres layers were studied. They also used a theoretical model, based on the rules of mixture, to predict the tensile strength of these hybrid composites. The obtained results showed that the tensile properties of flax–glass fibres reinforced hybrid composites were improved with the increasing of the relative volume fraction of glass fibres. The position of glass fibre layers had a great effect on the tensile strength of all hybrid

* Corresponding author.
E-mail address: el-hadi.saidane@univ-reims.fr (E.H. Saidane).

http://dx.doi.org/10.1016/j.compositesa.2016.04.023
1359-835X/

composites contrary to the tensile modulus, which was almost the same. Furthermore, a good consistency between the theoretical values and the experimental data was observed.

These works clearly show the complementary potential between natural and traditional fibres. However, only mechanical and dynamical characterisations could be, in some cases, insufficient particularly when hybrid materials are used in moisture environments. Within this context, other research works studied the effect of the addition of glass fibres on water absorption of natural fibre reinforced composites [27–30]. For example, Panthapulakkal and Sain [27,28] investigated the effect of water absorption on thermal and mechanical properties of short hemp-glass fibres reinforced polypropylene hybrid composites. They observed that the hemp-glass hybridisation enhanced the thermal and mechanical properties as well as the moisture resistance. Similar observations, about the hybridisation effect, were drawn by Vieira et al. [29] in the case of unsaturated polyester based jute–glass fibres hybrid composites.

All these research works showed the strong interest of using the hybridisation of natural fibre composites with synthetic fibres, in particular glass fibre, to improve their mechanical properties as well as the moisture resistance. However, it is also necessary to assess the hybridisation effect on the water uptake and the diffusion coefficient of the hybrid materials in hot and humid environment, in particular when the temperature is high. The present work focused on the investigation of hybridisation effect on diffusion kinetic and mechanical properties of twill weave flax–glass fibres reinforced hybrid composites. For this purpose, the non-hybrid and hybrid composites were elaborated by platen press process and subjected to hydrothermal ageing (immersion into water at 55 °C). Next, the collected experimental data of water uptake of aged materials was analysed by using an optimisation program of Matlab software in order to assess diffusion parameters. Finally, tensile tests were made on unaged and aged materials to determine the effect of the hybridisation associated with ageing on the evolution of their mechanical properties.

2. Materials and methods

2.1. Materials and manufacturing process

The flax fabric of 350 g/m^2 (marketed by Depestele Group) and glass fabric of 300 g/m^2 (marketed by Sicomin Company) were used in this work as reinforcement of polymer matrix. The weave was a 2/2 twill weave with the density of 1450 kg/m^3 for the flax fibre vs. 2450 kg/m^3 for the glass fibre. The matrix used for manufacturing the composite materials was a SR 1500 epoxy resin with SD 2503 hardener at a mixing ratio of 100:33 by weight.

Table 1
Layer configuration, thickness and fibre volume content of hybrid laminates.

Laminate designation	Plies number		Layer configuration	Nominal thickness (mm)		Fibre volume content	
	Flax	Glass		Flax	Glass	Flax	Glass
Flax fibre laminates	10	0	FFFFFFFFFF	4.84	0.00	0.40	0.00
$[G/F_4]_s$	8	2	GFFFFFFFFG	3.56	0.39	0.35	0.06
$[G_2/F_3]_s$	6	4	GGFFFFFFGG	2.67	0.77	0.31	0.11
$[G_3/F_2]_s$	4	6	GGGFFFFGGG	1.78	1.16	0.20	0.24
$[G_4/F]_s$	2	8	GGGGFFGGGG	0.89	1.54	0.15	0.35
Glass fibre laminates	0	10	GGGGGGGGGG	0.00	1.92	0.00	0.53

F: Flax fabric, G: Glass fabric, s: symmetric stacking sequences.

Six types of non-hybrid and hybrid laminates composed of 10 layers were prepared with different stacking sequences as summarized in Table 1. Laminate plates of 450 mm × 300 mm were manufactured by compression moulding. Firstly, flax and glass fabrics were manually pre-impregnated with the resin system. Next, the impregnated layers were placed one over the other according to the same orientation with resin layers. The whole assembly was carefully placed between two steel platens covered with Teflon paper. Laminates were then cured in a compression moulding machine (SATIM model) under 5-bar pressure at 35 °C for 3 h, following the supplier's recommendations. Finally, the laminate plates were cut and shaped in rectangular form (20 mm × 247 mm) according to ASTM D3039-76 standard by using a diamond saw blade. The thickness and fibre volume fraction V_f of different composites are given Table 1.

2.2. Water absorption testing

Edges perpendicular to the thin direction (z direction) of several tensile samples were polished and clogged with silicone. This protection prevented water absorption through the edges, in order to privilege the diffusion in the thin direction. The other samples were only polished and had no protection. Next, after being dried in an oven at 60 °C during 72 h, each batch of tensile specimens was subjected to water immersion at 55 °C. Temperature of 55 °C was used to accelerate the ageing mechanisms. The tensile specimens of each composite were removed from water, wiped with a dry cloth and regularly weighed during 38 days with a balance of ±1 mg precision. This duration was chosen to be sure that the weight of all tensile specimens reach the equilibrium plateau. After various periods of time, the water absorption characteristics of the composites were assessed by the relative uptake of weight defined by M_t according to:

$$M_t = \frac{W_t - W_0}{W_0} \times 100\ (\%) \tag{1}$$

where W_0 is the weight of the dry specimen and W_t is the weight of the wet specimen at time t.

More generally, in vegetable fibre reinforced polymer composites, moisture uptake follows a Fickian behaviour. In literature, several models have been developed in order to describe the moisture absorption parameters of composite materials. In the case of one-dimensional approach, Fick's laws show that the water uptake increases linearly with the square root of time, and then gradually slows until an equilibrium plateau is reached. In this case, the expression of Fick's solution is given as follows:

$$R = 1 - \frac{8}{\pi^2}\sum_{i=0}^{\infty}\frac{1}{(2i+1)^2}\exp\left(\frac{-(2i+1)^2\pi^2 D_z t}{h^2}\right) \tag{2}$$

where $R = M_t/M_\infty$, M_∞ is the maximum moisture uptake at equilibrium state, D_z is the diffusion coefficient and h is the thickness of the specimen.

With the aim of determining D_z and M_∞, an analytical modelling by using optimisation toolbox of Matlab was applied to experimental data obtained from the aged samples. This optimisation was based on the minimisation of the quadratic error (Eq. (3)) between the measured $R^M = M_t/M_\infty$ from experimental curves and the predicted R calculated from Eq. (2):

$$q = \sum_i \left(R_i^M - R_i\right)^2 (i = 1, 2, \ldots .n) \tag{3}$$

where n is the number of data points.

Values of the two parameters D_z and M_∞ were then varied until q is minimum, i.e. until the moisture contents predicted by the analytical solution converge with those deducted from the