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Multi-scaled enhancement of damping property for carbon fiber reinforced composites

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ABSTRACT

In this paper, a multi-scaled methodology by using flax fibers and carbon nanotubes (CNTs) was proposed to enhance the damping property of carbon fiber reinforced epoxy composites. The damping property was measured by free vibration test and the strength and modulus were obtained by tensile and flexural tests. Effects of stacking sequences of flax fibers and the addition of CNTs on both the damping property and the mechanical properties of carbon fiber reinforced composites were investigated. Results clearly showed that the damping property of carbon fiber reinforced composites was improved greatly by laying flax fibers on the outmost layers of the composites. With the addition of CNTs, the damping property was further enhanced. Damping modification mechanisms by hybridization with flax fibers and addition of CNTs were analyzed with the aid of the scanning electronic microscopy (SEM) and theoretical analysis. Results showed that the improved damping property of the hybrid composites was due to the internal sliding friction inside the flax fibers caused by the unique multi-scaled microstructure of the fibers and the stick-slip action of CNTs.

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1. Introduction

Carbon fiber reinforced polymer composites (CFRP) have been widely used in aerospace, construction, sports equipment, automotive and marine industries [1–4] due to their excellent mechanical properties and physical performances. However, the high stiffness of CFRP generally lead to a relatively low damping property due to the poor viscoelastic nature of carbon fibers. This has severely restricted their applications in working conditions such as vibration, periodic loading and external impact. For example, micro-cracks in CFRP structures will propagate rapidly under vibrational fatigue loading, resulting in premature failure [5,7]. Actually, vibration damping capability is a crucial parameter that affects performances, safety and reliability of a system. It refers to the elimination of mechanical energy by converting it into other forms of energy (usually heat). This kind of energy dissipation leads to numerous benefits, such as noise reduction, long service life and good control of the CFRP structures [6].

Therefore, how to enhance the damping property of carbon fiber reinforced composites has become a research hotspot in recent years. A few methods have been reported which included inserting co-cured viscoelastic layers, fiber coating, hybridization with other fibers and addition of nanofillers, etc. [6,8]. However, among these methods, co-curing viscoelastic layers increased the weight of the composites and fiber coating technique is relatively complicated. Hybridization with other fibers and addition of nanofillers are rather simple and are direct methods to enhance the damping property by introducing more internal interfaces which may cause energy dissipation.

Hybridizing more than one type of fibers in a composite can achieve a balance of each individual type of fibers and enhance the properties of the composites in order to meet various requirements [10,17]. Therefore, a number of researchers have embarked on enhancing damping properties of carbon fiber reinforced composites by hybridization with other synthetic fibers like glass fibers or aramid fibers whose damping property is much better than that of carbon fibers. Plant fiber, as a promising material for the reinforcement, displays many distinct advantages over its synthetic counterpart, such as low density, good sound absorption [25] and thermal insulation [26], high specific mechanical properties [9,10] and relatively high damping properties [25] specifically caused by its unique multi-scale microstructure. Therefore, they have been

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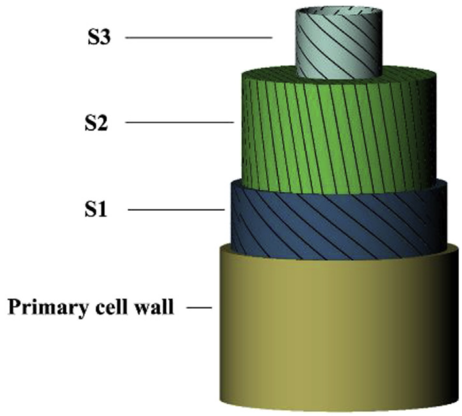

Fig. 1. Multi-scale structure of an elementary flax fiber [12].

particularly applied in the fields where the dissipation of mechanical or other types of energy are desired [11].

A single plant fiber is normally made up of a bundle of sub-fibers, which are normally called elementary fibers. At the microscopic scale of elementary fiber as schematically shown in Fig. 1 [12], it can been seen that each elementary fiber is made up of concentric cell walls called primary cell wall and secondary cell wall. The secondary cell wall is composed of three layers, namely S1 layer, S2 layer and S3 layer. Most of the cellulose microfibrils are located in the S2 layer [27]. It was found that vibration damping in flax fiber was attributed to the friction between the cellulose microfibrils and the polymer matrix within cell walls and between adjacent cells in fiber bundles [11]. At the center of the elementary fiber, there is an open channel called lumen which may also contribute to the damping property [12–15]. The chemical composition also defines the properties of flax fiber. The main chemical composition of flax fibers is cellulose [18], which is a type of polymer and possesses viscoelastic property, like other polymeric materials. Moreover, the specific mechanical properties of flax fiber are comparable to those of glass fiber, as shown in Table 1 [13,16]. Therefore, hybridizing flax fibers with carbon fibers may improve the damping property of the composites and at the same time may lead to increased specific mechanical properties. Assarar et al. [19] measured the specific damping coefficients of carbon fiber, flax fiber and their hybrid reinforced composites. Results showed that hybridizing flax fibers into carbon fibers can improve the specific damping coefficient of CFRP. However, only modeling and analysis by finite element method was attempted without considering the contribution of the unique microstructure of flax fibers on the damping property.

Carbon nanotubes (CNTs) are ideal nanoscale reinforcing materials for polymeric composites due to their excellent strength and elastic modulus. Adding CNTs into composites can cause an interfacial slipping and associated friction, which can be employed to improve the damping property of the composites. Besides, the interaction between carbon nanotubes may also contribute to the enhancement of damping property [20]. Generally, there are two routes to incorporate CNTs into polymeric composites. One is to disperse CNTs into liquid matrix resin with the help of hand stirring, ultra-sonication [21] or high pressure homogenization [22]. Another approach is to deposit or coat CNTs on the surfaces of reinforcing fibers by using chemicals, electrophoresis, chemical vapor deposition (CVD) and spray-up processing [21]. Khan et al. [5] used a CVD method adding multi-walled carbon nanotubes (MWCNTs) into epoxy resin and fabricated CFRP. The free vibration test showed that the damping ratio of modified CFRP increased by about 20% when CNT content was increased from 0.5% to 1.0%. Tehrani et al. [23] used a relatively low temperature synthesis technique called graphitic structures by design and grew CNTs on the surface of carbon fibers. The damping property of the modified CFRP was evaluated by dynamic mechanical analysis which indicated that the loss factor of the resultant composite was improved by 56% compared to that of the controlled specimens.

Considering the multi-scaled structure of plant fibers and the easiness of deposition of functional CNTs onto plant fibers due to the existence of a large amount of active hydroxyl groups, in this study, a multi-scaled methodology was applied to make carbon fiber reinforced composites. Effect of stacking sequences of carbon fabric layer and flax fabric layer on the damping property of the hybrid composites were investigated. Furthermore, CNTs were deposited on the surfaces of flax fibers and the multi-scaled carbon/flax-CNTs hybrid composites were fabricated. The damping modification mechanism was studied systematically. Besides, the tensile and flexural properties of these hybrid composites were also investigated to study the changes of mechanical properties of this multi-scaled CFRP composites.

2. Experimental

2.1. Materials

The unidirectional T300-3K carbon fabric was supplied by Heroman Co. Ltd, USA with a fiber density of 1.78 g/cm^3 and an areal density of 180 g/m^2. The unidirectional flax fabric was supplied by Lineo Co. Ltd, Belgium with a fiber density of 1.50 g/cm^3 and an areal density of 200 g/m^2. Bisphenol-A-based epoxy resin, anhydride-based curing agent and tertiary amine-based accelerating agent were supplied by Nanya Electronic Materials Co. Ltd, China. The carboxyl-functionalized multi-walled carbon nanotubes (MWCNTs-COOH) were purchased from Chengdu Organic Chemicals Co. Ltd, China (Fig. 2). They are specified with average inner and outer diameters of 3–5 nm and 8–15 nm, respectively. The length of the CNTs is up to 50 μm. The carboxyl content is approximately 2.56 wt% and the carbon purity exceeds 95%.

Table 1
Properties of plant fibers, glass fiber and carbon fiber [13,16].

Fiber	Density (g/cm^3)	Tensile Strength (MPa)	Young's Modulus (GPa)	Specific Strength (GPa cm^3/g)	Specific Modulus (GPa cm^3/g)	Elongation at failure (%)
Flax	1.50	345–1100	27.6	0.2–0.7	18.4	1.2–3.3
Jute	1.3–1.4	393–773	13–26.5	0.3–0.5	10–18.3	1–1.8
Ramie	1.50	400–938	61.4–128	0.3–0.6	40.9–85.3	1.2–4.0
Sisal	1.45	468–640	9.4–22.0	0.3–0.4	6.4–15.2	2.0–7.0
E-glass	2.5–2.6	2000–3500	70–76	0.8–1.4	29	1.8–4.8
Carbon (T300)	1.76	3500	230	1.99	131	1.5

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