Analysis of Multi Scale Structure for Plant Fibers

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Abstract. Based on Hamiltonian theory, a boundary integral method is developed to deal with complex boundary conditions and interface continuity conditions. In addition, based on the micro experiments, the characteristics of micro multi-level structure of plant fibers are systematically studied, and the computational mechanical models of each level are established. Based on Hamiltonian theory, a boundary integral method is developed to deal with complex boundary conditions and interface continuity conditions. In addition, based on the micro experiments, the characteristics of micro multi-level structure of plant fibers are systematically studied, and the computational mechanical models of each level are established.

1. Introduction

With the increasingly serious problem of environmental protection, the development and application of new environment-friendly composite materials are highly concerned by researchers and even government departments in various countries [1, 2]. As we all know, plant fiber is a kind of natural polymer material widely existing in nature, and it is the largest renewable resource in the earth's biological resources. From the perspective of its own structure, plant fiber is a natural green composite material carefully designed by nature and presented to human beings, and also an ideal reinforcement for designing various composite materials [3, 4]. For example, Phyllostachys pubescens, which is rich in southern China, has a multi-level biological composite structure from the subcellular level, cell level, tissue level to the macro scale, with small density, high strength, good elasticity and stable performance. The results show that the high-strength properties of Moso bamboo materials mainly come from the fiber bundle, and the strength of the fiber bundle depends on the fiber cells. The fiber cells have the micro nano structure composed of the primary wall and the thin and thick alternately. This unique cell wall structure is the basis of its excellent macro mechanical properties, and also makes the bamboo fiber often selected as the natural reinforcement of various composite materials. In addition, many other plant fibers, such as hemp, also have special bio composite structure, and are often used to develop the reinforcing phase of green composite materials.

Compared with synthetic fiber, plant fiber has a wide source, can be easily extracted from natural plants, has higher strength, smaller density, biodegradation, and low cost. The results show that rice husk fiber can improve the tensile and bending properties of HDPE, wood powder can improve the thermal and mechanical properties of PP composite, Hemp Fiber Filled PP composite has better tensile, bending and impact strength. Due to the inherent performance advantages of plant fiber, it is very suitable to be an ideal reinforcement of high-performance and environment-friendly composite materials. Taking natural plant fiber as the reinforcement material, it has opened a new way for the
research of reinforced composite materials. Mohsen et al. studied the composites based on polypropylene reinforced by banana fiber, and quantitatively proved that banana fiber, as the reinforcement phase, can play an important role in improving the overall tensile and energy absorption properties of the materials. Badar et al. carried out tensile experiments on the yarn reinforced polymer composite, studied the creep and stress relaxation of the material, and pointed out that the fiber material significantly improved the overall mechanical properties of the composite [6]. Saba et al. discussed the time and temperature dependence of dynamic parameters such as storage modulus and damping factor [7].

2. Boundary integral method based on Hamiltonian system

Because the Hamiltonian system adopts the dual form of basic variables, it can easily describe the boundary conditions. For this kind of problem, the given boundary condition can be expressed as the combination form of the eigensolution function, so that the problem can be transformed into the solution of the expansion coefficient of the eigenfunction to be determined. Because the number of the coefficients to be determined in the equation is the same as that of the eigensolution function, the eigensolution vector of each order can be used in turn as the weight function to carry out the weighted integration of the expansion equation on the curve, and the closed algebraic equations about the coefficients to be determined can be established. The above methods are expressed in mechanics as follows:

$$\int q_{k,l} \otimes p_m^{(a)}ds = \int \left( \sum a_{i} e^{x^{i}q_{s}^{(a)}} + \sum b_{i} e^{x^{i}q_{s}^{(b)}} \right) \otimes p_m^{(a)}ds \quad (m = 0, 1, 2, \cdots, N) \quad (1)$$

and

$$\sigma_{ij}(t) = \int^{t}_{-\infty} \frac{E(t-\tau)}{1 + v} \partial_{\tau} e_{ij} d\tau + \int_{-\infty}^{t} \frac{v E(t-\tau)}{(1 + v)(1 - 2v)} \partial_{\tau} e_{ij} d\tau \quad (2)$$

According to the mechanical properties of the minimum scale obtained from the microstructure observation experiment and measurement, we take the minimum level microstructure as the starting point, adopt the research idea of layer by layer analysis and level by level promotion, and pass the mechanical properties of the minimum scale as the composite inclusion phase or matrix to the next level. Based on the boundary conditions and interface continuity conditions of composite materials, the eigensolution expansion equation is established, and the equivalent mechanical properties of this level are calculated, which are transferred layer by layer until the equivalent mechanical properties of each level are obtained. Compared with the mechanical parameters obtained from the tensile experiment of plant fiber, the mechanical model of composite materials is tested. At the same time, according to the calculation results, we study the influence of the material properties, volume content and interface layer parameters on the macro mechanical properties of the plant fiber, and analyze the load transfer mechanism between the micro structures of the plant fiber.

3. Microstructure of plant fiber

The plant fiber is dried at 85 °C for 12 hours in a constant temperature air blast drying oven, and then the polymer powder is dried at 80 °C for 2 hours. The plant fiber and polymer powder are mixed in a certain proportion according to the mass ratio, and then the maleic anhydride grafted polymer powder accounting for 2% of the total mass of the material is added and mixed in a three-dimensional mixer. At last, move the mixed raw materials into the mold, and put them on the flat vulcanizer for molding. The molding temperature is set to 175 °C, the pressure is 10 MPa, and the holding time is 10 min. The final size of the composite material is 120 mm × 100 mm × 10 mm. After the mold is cooled to room temperature, it is taken out and processed into a standard sample.

The orthogonal design method was used to design the experimental scheme of different kinds of reinforced fiber, different molding temperature and different holding time. The compression test of the composite block was carried out, the load and displacement curves were recorded, the compressive
strength of the composite was measured, the crack resistance of the composite block was observed, and the performance of the composite was evaluated.

According to the comparative analysis of the experimental results, the design theory and calculation results of the plant fiber-reinforced polymer composite were tested to find the best ratio of the composite materials and realize the design and optimization of the new composite materials.

Based on the scanning results of cross-section microstructure of hemp fiber shown in Fig.1, the cross-section of hemp fiber can be approximately regarded as a three-level microstructure, in which the lumen is the first level microstructure, a large number of lumen clusters are the second level
microstructure, and a large number of clusters constitute the third level microstructure. A preliminary three-layer and multi-scale thermal model is established (shown in Fig. 2). The microstructure of hemp fiber is studied. The thermal conductivity of the corresponding components is calculated by the multi-scale method, and some results are consistent with the existing data.

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