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Improvement of Mechanical Properties of Wood-Plastic Composite Floors Based on the Optimum Structural Design**

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ABSTRACT A study is carried out on the structural design of wood-plastic composite floors. The geometric parameters of the cavities, the structure, and the means to optimize the performance of these light boards are investigated. Various structural parameters of the boards, such as size, shape, and the pattern of cavities are also studied. The optimal structure can be determined by calculation and analysis of the strength, stiffness, weight and cost of the material. A finite element model for the mechanical analysis of wood-plastic composite floors is established; and the results are used to verify the strength criteria under bending deformation, which is the most common loading condition of flooring board.

KEY WORDS wood plastic composite, cavities, flooring board, optimal structure, the finite element model

I. Introduction

Wood is the only renewable, eco-friendly and recyclable material that can form a healthy, comfortable and natural part of our living environment. However, because the improvement of life quality in China has raised the demand for timber, China has been experiencing an acute shortage of forest resources. The discrepancy between timber supply and demand has long been a critical issue, which has made the search for alternatives to wood the most obvious solution to the problem. Fiber-reinforced plastic composites have come into wide use over the last decade, and have relieved the demand for timber resources to some extent. In the early 2000s, the output of natural fiber/thermoplastic composites in North America and Europe reached 68.5 million tons, including 590,000 tons of wood-plastic composites made of a range of wood fibers from different sources that accounted for 87% of the total output[1]. Wood-plastic composites are green biomass materials using plastics as matrices and fibers of wood or bamboo as reinforcements, which have gradually become an important type of functional materials with the development of science and technology. Compared with traditional wood, wood-plastic composites possess the hardness of plastics and the process ability of thermoplastics. These composites can also be reused and recycled. Furthermore, wood-plastic composites are biodegradable, highly resistant to insects and rot, and have low water absorption capacity. These characteristics make the materials more

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durable than natural wood[2–5]. So far many studies have been made on the mechanical properties of biomass fiber/plastic composites. To name just a few, Bengtsson et al.[6] investigated the application of a silane coupling agent in wood-plastic composites and analyzed their mechanical properties; Liu et al. and Yao et al.[7,8] studied the effects of different types of coupling agents and their proportions on the mechanical properties of high-density polyethylene (HDPE) composites reinforced with rice straw or bamboo fiber, analyzed the influence of different coupling agents on the interfacial properties of composites, and tested their impacts and tensile strengths; Yao and Wu[9] studied the manufacturing process of the core-surface structure of wood-plastic composites, as well as the influence of surface properties on the impact strength.

Flooring boards are subject to varying degrees of stress, which is particularly the case for the floors in public buildings and outdoor spaces. The mechanical strength of floorboard is closely related to its service life and safety of users. When used outdoors, ordinary wooden floorboards experience climate change and may rot, which increases the risk of damage and the cost. Several lightweight, corrosion-resistant and aesthetically pleasing wood-plastic composite flooring materials have recently become available and are widely used in outdoor gardens, hiking trails, and public parks. The design of lightweight floors is currently an important industrial issue because of the enormous demand for floorboards to comply with national standards. To reduce both the cost and the degree of effect upon the environment, besides meeting the strength requirements, the amount of flooring material used should be minimized, as should the amount of energy consumed during production.

Currently the lightweight design technology has been widely applied in many fields. For example, Ying and Jian[10] used a designed tower plate for a wind generator with a unique lightweight cross-sectional structure. Wang et al.[11] significantly reduced the weight of passenger train floors by using a modular floating floor with elastic sealing structure. Ringsberg et al.[12] investigated the design of lightweight structures for offshore platforms. Meschut et al.[13] designed a lightweight structure for car bodies. However, few studies have been reported on the structural design of lightweight wood-plastic composite floors.

In the present study, an optimized flooring board design with cavities to reduce mass is offered. Analysis of the strength, stiffness, weight and cost of flooring boards with different types of core-cavity has been done using mechanical strength theory. A theoretical method is proposed to analyze and optimize the cross-sectional design of extruded wood-plastic composite flooring board.

II. Modeling and Simulation

2.1. Common cavity structure of wood-plastic composite floors

The wood-plastic flooring boards now in common use can be either solid or hollow. The cross-sectional shape of the cavities in hollow floors can be circular, rectangular, oval, or rectangular with rounded corners, as shown in Fig.1. The cavities are usually evenly spaced across the width of the board and their number can vary significantly. Most wood-plastic composite flooring boards have cylindrical cavities. The rectangular cavities with rounded corners are also common; but the oval shaped ones are rarely used. The cross sectional shape of the cavity is determined by the required strength of the board, which can facilitate the manufacturing process. The overall performance of a rectangular cavity is close to that of one with sharp corners, because the actual radius of the rounding is quite small. However, the calculations needed for the determination of the load bearing properties are complicated and in this study the discussion will be limited to the analysis of the properties of wood-plastic composite flooring boards with cylindrical and rectangular cavities.

2.2. Assessment of the cross-sectional design of wood-plastic floors

Wood-plastic floors are required to have a reliable and constant load bearing capacity and a certain degree of hardness, which depend on the service conditions. At present, the international market regulations impose few requirements with respect to these wood-plastic floors. China has only one National Standard, which stipulates the bending failure load. The related contents are quoted as follows.

Table 1 shows that according to the National Standard, the requirement for wood-floor strength is based on the application of the product in public and non-public places, where different regulations apply. In this study we have confined our attention to the use of wood-plastic composite flooring boards in public places, where the strength requirement is high. Flooring of this type used in non-public places