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Mass-specific flexural properties of a mycelium-based biocomposite

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***Abstract*- Over the past few years, development of technology at the intersection of material sciences and biology has led to introduction of new generations of eco-friendly, engineered materials composed of biocompatible and biodegradable natural components. Mycelium-based biocomposites made of wood fibers embedded in a dense fungal matrix exhibit physical and mechanical properties comparable to their synthetic counterparts like Polystyrene foams which are widely used in packaging, thermal/acoustic insulation, and construction industries. In this study, two prismatic samples of a mycelium-based biocomposite were fabricated by controlled growth of a fungal mycelium species forming the binding matrix within wood fiber substrates made of chopped leaf sheaths of date palm with different sizes. Both samples were tested under quasi-static displacement-controlled three-point bending, and their mass-specific flexural properties were measured. Results showed that the sample with larger fibers exhibits less strength, where larger empty spaces in the fibrous network prevent the growing matrix from consolidation.**

Keywords: Biocomposite material; natural fibers; fungal matrix; flexural properties

I. INTRODUCTION

In recent decades, uncontrolled generation of non-biodegradable polymeric wastes in packaging industries, as a result of rapid growth of technology, has become a global environmental crisis. Moreover, production of synthetic foams, including Polystyrene (Styrofoam) and Polyurethane, requires high energy embodied process and use of non-renewable resources. Recent advancements in biomaterials science and engineering have led to introduction of sustainable materials, such as mycelium-based biocomposites (MBCs), potential alternatives to synthetic foams. These bio-based materials are manufactured by controlled growth of fungal species within the natural wood substrate, and can be used for packaging, thermal and acoustic insulation, and construction [1–4]. In this study, flexural properties of a mycelium composite comprising natural chopped fibers made of leaf sheath date palm waste and a fungal mycelium species as the growing matrix were measured. For the flexural test, two samples with different fiber sizes subjected to the same pre-pressure were fabricated and tested under quasi-static displacement-controlled three-point bending and the effect of fiber size on flexural properties of these bio-foam specimens were studied.

II. MATERIALS AND METHODS

Natural Components

Vegetative form of culinary-medicinal king oyster mushroom (*Pleurotus eryngii*), forming the matrix phase, is a self-growing binding agent to cohere the natural fibers together, and helps providing an eco-friendly biocomposite fabrication process. Moreover, lignocellulosic waste fibers are used as the reinforcements considering the fact that they can provide the cellulose or lignin in plant biomass for mycelium growth [5]. The lignocellulose leaf-sheath date palm fiber waste has the highest cellulosic content, nearly 50 %, compared to the Coir, Sisal, and Hemp, and its lower density in comparison with other natural fibers makes it suitable for natural fiber biocomposites fabrication [6]. In this research, the fibers were sifted into two statistically distinguishable sizes. The diameter and length of large fibers vary from 0.5-4.7 mm and 9-55.5 mm, respectively, while the small fibers vary from 0.2-3 mm in diameter and 5.3-41.5 mm in length.

Sample Preparation

The thickness, width, and length of prismatic specimens are 20±5, 60±5, and 180±5 mm, respectively. 30% wt (weight percentage) of dry materials, including the fibers and added wheat bran (for nutrition support) with a relative weight ratio of 1 to 4, were mixed with 37% wt water, followed by inoculating the remaining 33% wt of mycelium spawn. The mixture was kept in plastic bags for 7 days in an incubator at 27°C and 60% relative humidity for the initial incubation. After molding, fairly identical pre-load of 18 kg on the largest side was applied to both samples and the mycelial network continued to grow in the molds for 21 days. After demolding, the samples were kept being incubated for 7 more days to unfirm the fungal network growth on the lateral sides.

Flexural Test

The quasi-static displacement-controlled three-point bending test was conducted using the Zwick Z250 testing machine with 2 N preload and 1 mm/min crosshead speed. The bending test was terminated at around 5 percent strain when rupture occurs in the outer surfaces of the test specimen and the recorded force-displacement data was used to find the stress-strain responses based on definitions in ASTM C203-05a and ASTM D790 materials testing standards.

Fig.1: Flexural testing

III. RESULTS AND DISCUSSION

The recorded load-displacement curves of both samples showed two distinct regions as the displacement continuously increased. Specimens initially showed an almost linear elastic behavior with a constant elastic (flexural) modulus until the visible signs of bending failure were revealed with abrupt drop of measured force. At the start of progressive failure, the binding interfaces between the fiber and matrix phases seems to be annihilated resulting in the decrease of bending strength. According to Table I, the specimen fabricated with large fibers show smaller flexural strength, specific flexural strength, and elastic modulus. This can be justified considering that the vacancies in the fibrous network are greater here compared to the sample with small fiber, preventing the growing matrix from consolidation. Although the biocomposite samples tested in this study show weaker (but comparable) flexural properties than their synthetic counterpart Polystyrene (with flexural strength of >70 kPa), it is important to note that only the effect of fiber size on flexural properties of the biocomposites was studied here, and there is still great room for improvement considering that different parameters such as the types of ingredients and composition, growth period, pre-pressure, etc. can be modified accordingly to optimize their flexural behavior [4].

TABLE I: SUMMARY OF FLEXURAL PROPERTIES FOR SPECIMENS WITH DIFFERENT FIBER SIZES.

Fiber Size	**Density (kg/m^3)**	**Flexural Strength (kPa)**	**Specific Flexural Strength (kPa/kg)**	**Elastic (Flexural) Modulus (MPa)**
Small	153.22	21.9	491.2	2.98
Large	153.83	11.7	283.4	1.29

IV. CONCLUSION

In this study, two samples of mycelium biocomposites with different fiber sizes but identical fabrication and testing protocols were tested under quasi-static displacement-controlled three-point bending, and the effect of fiber size on their flexural properties was studied. The experimental results showed that these fully bio-based materials are comparable to Polystyrene (classified as foam materials) in terms of flexural properties, and the specimen with large fibers exhibits lower flexural properties such as specific flexural strength and modulus.

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