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PROCEEDINGS

Editor Dr Milica Vlahović

Belgrade, November 02-03, 2023

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on Renewable Electrical Power Sources

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POSTUPAK IZRADE POLIMERNOG KALUPA ZA ISPITIVANJE NA ISTEZANJE BIOKOMPOZITNIH MATERIJALA

POLYMER MOULD MANUFACTURING FOR TENSILE TESTING OF BIOCOMPOSITE MATERIALS

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Apstrakt

Proizvodnja i primena biokompozita je značajno doprinela smanjenju upotrebe nebiorazgradivih materijala. U opštem smislu, biokompoziti se sastoje od biorazgradivih prirodnih polimera (biopolimera) i ojačavajuće faze-biovlakana. Biovlakna su glavni sastojci ovih materijala i mogu biti različitog prirodnog porekla (pamuk, lan, konoplja, micelije gljiva, reciklirano drvo, agroproizvodi ili regenerisana celulozna vlakna). U ovom radu, testiran je i razvijen kalup za biokompozite na bazi micelijuma i odgovarajućeg supstrata (pšenične slame). Osnovna namena kalupa je priprema i očvršćavanje bio materijala da bi bilo omugućeno ispitivanje u skladu sa standardima ASTM D7250 i ASTM D1037, koji su namenjeni ispitivanju uzoraka na istezanje i pritisak. Izrada i oblikovanje biokompozita predstavljaju tehnološke postupke koji se sprovode u cilju sušenja i smanjenja procenta vlage nakon zasejavanja, pri čemu je gornji deo perforiran zbog isparavanja i što boljeg očvršćavanja uzoraka. Za proizvodnju kalupa upotrebljen je PLA termoplastični filament. Kalup je izrađen kao dvodelni sklop, oblika "dog bone" u skladu sa pomenutim standardima. Ovako pripremljen i sklopljen kalup je moguće primeniti i za ispitivanje ostalih biokompozitnih struktura (mešavina različitih vrsta fungi i odgovarajućih supstrata).

Ključne reči: *biokompoziti; termoplastični polimeri; ispitivanje istezanjem*

Abstract

The manufacturing and application of biocomposites are remarkable achievements in replacing conventional non-biodegradable materials. In general, biocomposites are made up of biopolymers and bio-based reinforcing agents. Biofibres are also the main constituents of biocomposites, which are generated from biological entities such as crop fibres (cotton, flax, mycelium of fungi, hemp), recycled wood, wastepaper, agro-based by-products or regenerated cellulose fibre. In this paper, a mould intended for biocomposites based on mycelium and an adequate substrate is tested. The primary purpose of the mould is to bring the loose natural material into a solid preparation following the standards ASTM D7250 and ASTM D1037, which include testing the technologically prepared and hardened sample for tensile and pressure. Development and moulding of biocomposite are the technological processes of drying after sowing mycelium so that a variant of the mould with a perforated upper part was used to harden the samples thoroughly. In the mould, realization is used PLA thermoplastic filaments. Mould was made as an assembly of two parts, and *its shape is like a dog bone, according to the mentioned standards. This polymer enclosure is helpful for other biocomposite structures (a mixture of different fungi species and adequate substrates).*

Key words: *biocomposite; thermoplastis polymer; tension test; moulding*

1 Introduction

Many innovations in architecture and construction are related to the production of building materials and the realization of buildings from biological materials. Today, mushroom-based biocomposites are the most common, where mushroom roots (mycelium) firmly hold shredded cellulose material from agricultural waste or sawdust during wood processing in the wood industry.

Biocomposite materials based on mycelium have found application in producing ecological house blocks and packaging material. Designers and architects began to use mycelium-based products such as kitchen utensils [1], packaging items [2], building blocks, and wall and ceiling panels [3-4]. Also, biocomposites are promising and environmentally acceptable because they replace standard material and cancel the presence of carcinogenic substances [5]. This material is ecologically advantageous and represents an alternative to polystyrene and plastic packaging.

Using biomaterials in construction is one of the indicators of sustainable development because mushrooms represent a renewable biological resource. The construction industry, using the conventional production of materials, consumes a lot of energy, which is also harmful to the environment. Consumed power represents between 20% and 40% of total production costs [6]. Blocks made of mycelium are 80 times cheaper than gypsum blocks [7]. The advantages and disadvantages of using mycelium-based biocomposites are presented in Table 1 [1, 7, 8-10].

Table 1 – The advantages and disadvantages of using biocomposites

Advantages	Disadvantages
Very favourable production price.	High surface roughness.
They do not emit harmful gases.	Poor mechanical and hydrophilic properties.
They are not harmful to the environment	Quality production of parts only under pressure.
They are easy to make and shape.	The curing process is lengthy.
They represent renewable and biodegradable materials.	Durability of the product.
Excellent thermal and acoustic insulation.	
Good insulating material.	
They have good fire-fighting characteristics.	
They are very light.	
They have an excellent strength-to-weight ratio.	

2 Mechanisms of biocomposites manufacturing

The quality of the biomaterial depends on the type of mushroom, i.e. the presence of chitin in the mushroom mycelium, which plays a prominent role in substrate adhesion. According to sources [2, 7], the following factors are essential in choosing a substrate: (1) nutritional content, (2) availability, (3) degradability, (4) price, (5) structural properties and (6) compatibility.

Substrates with a high cellulose content (wood sawdust, straw, garden waste, and agricultural waste from vines [11]) allow fungi to overgrow, leading to a higher mycelial density and chitin content. Thus, the substrates are compatible with fungal growth, and the quality and speed of mycelium growth depend on the substrate type. The technology for making biocomposites in laboratory conditions is shown in Figure 1.

a) *b)*

Figure 1. Realization of a biocomposite block based on mycelium:
a) straw base, b) realized composite showing different granulation and distribution of fillers

Mycelium is a branched dense network of thin threads (hyphae) that grow and join to form a solid structure. The mycelium is the vegetative part of the mushroom consisting of branched tiny white filaments (hyphae) that penetrate and decompose the organic substrate to form a 3D matrix structure [9, 12]. The shredded cellulosic material is sterilized at a specific temperature to remove moulds and other microorganisms.

A fixed organic substrate is mixed with nutrients mixed with mushroom spores, followed by incubation to encourage mycelial growth [6]. To obtain specific shapes and, thus, the desired structure, mycelia are subjected to elevated temperatures. The mycelia then dry out and eventually die, as this prevents uncontrolled growth and swelling [1]. The experimental treatment of mycelium growth in a test tube is shown in Figure 2.

Figure 2. Monitoring the growth and density of the mycelium network in the test

Three phases are applied in the preparation of biocomposite production: inoculation phase, growth phase and ceasting phase. The inoculation phase includes preparing the mixture, decontamination and inoculation. Growth phases analyze the growth phase, while ceasting includes drying and heating [13].

When the mycelium grows, it increases the density in its substrate and, at the same time, binds to the substrate. The structure and strength of hyphae provide chitin in cell walls. Chitin is a rigid, inelastic linear polymer [14] which gives it rigidity. This bonding allows chitin to possess even increased tensile strength.

Suppose it needs to be done according to the defined criteria. In that case, many types of moulds appear (due to inadequate sterilization or contamination of the soil), which leads to the spread of unwanted microorganisms, and this results in the creation of carbon dioxide as well as the dispersal of anaerobic fungal spores, which pose a danger to the human respiratory system.

To obtain a biomaterial with a high density of mycelium, there must be no light radiation, and the concentration of carbon dioxide increases while reducing the concentration of oxygen and maintaining temperatures in the range of 18 ÷ 35 °C [15].

3 Moulds making for specimen testing

The most common moulding approach refers to the production of bricks or blocks, but pressure moulding of biocomposites is gaining more and more importance [16]. Biomaterials with mycelia are versatile and sustainable and can have simple or complex geometry. Also, by applying 3D printing, supplementary matrices made of bioplastics can be produced, which are additionally incorporated into the structure [17]. Making moulds from thermoplastic polymers enables the realization of a complex internal system. This is where the filling problem arises, as well as time constraints, i.e. the proportion of essential elements in the mixture.

In this work, moulds for biocomposite specimens were realized. Figure 3 shows the sample for the tensile test according to the ASTM D103767 standard [18]. Also, a 3-point bending test (until the sample breaks) is performed according to the ASTM D7250 and ASTM C393 standards, while the water absorption test, volumetric swelling and the change in sample thickness are analyzed according to ASTM D1037:2012 [19].

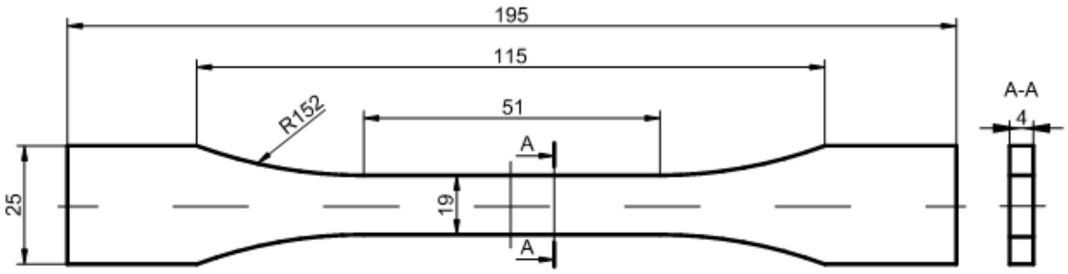

Figure 3. Specimen image according to the ASTM D103767 standard

A mould was made from the thermoplastic material PLA. A 3D printer manufactured by Creality Ender 6 Core-XY, with a work surface of 250×250×400 mm, a print speed of 150 mm/s and a printing accuracy of 0.1 mm, and was used to create the mould. This printer is functional when working with PLA AND PET-G filaments. The biocomposite moulding technique (in this case - under pressure), compared to many other moulding techniques, helps to reduce excess waste [20]. The set printing parameters are given in Table 2.

Table 2 – Basic model parameters

Parameter	Value
Layer height	0,15 mm
Wall thickness	0,6 mm
Top thickness	0,6 mm
Infill density	100 %
Infill pattern	Grid
Printing temperature	215 ^{0}C
Build plate temperature	60 ^{0}C
Print speed	50 mm/s

Figure 4 shows a realized two-part mould made of PLA. The base of the mould (1) and the mould cover (2) have holes arranged in a line to remove excess water from the mixture.

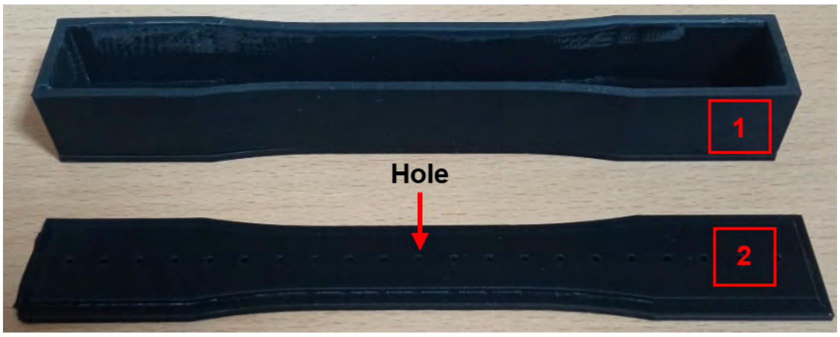

Figure 4. Realized two-part mould for the biocomposite specimens manufacturing

After pressing the substrate, a mushroom strain is placed, which begins to develop in a specific time interval. The development of fungi at a particular stage is stopped by drying or heating [1]. The outcome of this process is obtaining a biocomposite based on mycelium. Realized samples received a white cover of mycelium; see Figure 5. Pressed specimens (with mushroom seedlings) received a contour dictated by the shape of the mould, all following the ASTM D103767 standard.

Figure 5. Biocomposite specimens with an enlarged view of the mycelium sheath

The mycelium biocomposite density is calculated by measuring the mass and volume of the sample [21]. The testing of biocomposite materials includes evaluating the primary and mechanical properties. The drying process is a parameter that directly affects the mechanical and physical-chemical behaviour of the biocomposite [20].

Realizing moulds made of thermoplastic polymer enables easy production of different samples with different combinations of mushrooms and substrates, i.e. their share in the mixture. Various biocomposites should be provided with a sterile working environment and a developed method of productive moulding.

4 Conclusion

In this paper, we mentioned two technologies related to the complete realization of bio-composites according to the defined geometry. The first technology, which was not the subject of research, relates to the formation of biomaterials, which depends on several factors and is a separate topic for analysis. Another technology is described as essential as an auxiliary tool for forming a mould in which the biomaterial is shaped.

The PLA mould is defined according to the dimensions prescribed by the ASTM D103767 standard. The described steps in specimen manufacturing are: mould manufacturing, preparing and placing the mixture of biomaterials in the mould (according to all defined biological and chemical analyses), pressing the material according to the defined specimen shape, and finally, removing the specimen from the mould.

The improvement in the mould manufacturing would be reduced to the automation of making several specimens to monitor the behavior of one series. Also, in further investigation, it would be interesting to place a polymer matrix inside the biomaterial, which has mycelia's role in strengthening the structure of biocomposites.

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