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COMPRESSIVE RESISTANCE OF THE MYCELIUM COMPOSITE

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Abstract: *Compressive resistance of the mycelium composite*. Mycelium composites are a type of novel, economical and environmentally sustainable materials. The advantage of this material is that it forms a compact unit without the use of any adhesives. In this study mycelium boards were prepared from middle wood chipped particles for the manufacturing of commercial particle boards by using the growth activity of fungus *Trametes versicolor*. The compressive resistance of the mycelium composite was low but acceptable and comparable with other materials.

Keywords: mycelium composite, compressive resistance, *Trametes versicolor*

INTRODUCTION

About 30 million tons of wood waste is generated each year in the countries of the European Union. Much of the wood waste comes from the household (furniture, doors, windows, floors and the like) and production residues from wood industries (sawdust, sawmill particles, wastes from panel edging, particles). A very large fraction of waste wood still ends up in landfills or is widely recognized feedstock for wood-based composite (Merl et al. 2007, Dodoo et al. 2014, Laskowska–Mamiński 2018). This large volume of wood waste has new business opportunities and new markets through various projects, which makes a range of materials with low carbon footprint and economically competitive over the past decades available to companies.

In recent decades, new ecological and environmentally suitable materials made of wood or other organic substrates, colonized by mycelium have been developed as novel bio-based materials. Mycelium composites are made-up by inoculating an individual strain of fungi (hyphae) in a substrate of organic substances (Bayer et al 2011, Holt et al. 2012). Hyphal network (mycelium) degrades and colonizes the substrate, using the products of degradation as feeding elements to extend its hyphae from the tip. On the other hand, the mycelium branches new hyphae and fuses them together forming a denser network. Like a self-assembling biological binder, mycelium glues the substrate and provides its strength and integrity. Suitable media for a substrate can be retrieved from agriculture, like wheat or rice straw or husk, wheat grain (Ziegler et al. 2016, Jones et al. 2018), cotton carpel (Holt et al. 2012), corn stover (Tudryn et al. 2018), from waste wood chips (Yang et al. 2017) or from other natural fibres such as jute, flax, hemp, burlap, etc. (Lelivelt et al. 2015). What significantly influences the final properties of the resulting material is the type of chosen organic substrates, and how they are created. A bio-composite consisting of mycelium-plant material can be applied as a biodegradable alternative for a wide range of industrial materials as a replacement for non-renewable resource materials such as polystyrene, styrofoam or poly-urethane foams (Attias et al. 2017). There are different applications of the mycelium composite, such as:

- mycelium foams, which are created by baking the inoculated substrate to render the mycelium inactive (Bayer – McIntyne 2011, Holt et al. 2012, Pelletier et al. 2013, Yang et al. 2017). This material is usually used as a packaging material or as low density boards which are biodegradable, fire proof and water resistant;

- mycelium bricks, which are created by mechanically pressing the inoculated substrate at least once during the growing process in a rectangular form. When pressure is applied, the bonding becomes stronger between the secondary materials and the fungal mycelium, thus the material has higher density, and compressive and flexural strength (Ross 2016);
- mycelium boards – are created by pressing the inoculated substrate or low density boards under heat and high compressive pressure to achieve the desired densities (Pelletier et al. 2017). The mycelium particleboard, branded MycoBoard^{TM}, has application in work surfaces, moulded furniture components, seatbacks, architectural panels, door cores and cabinetry. It offers an environmentally sustainable alternative to particle board, plywood, and fibreboard traditionally produced from pressed and extruded wood chips and synthetic resin;
- mycelium sandwich panels – are fabricated using (epoxy) resin to adhere a mycology matrix core material to a top layer (a carbon fibre woven textiles layer, a laminate layer, etc.) (Travagliny et al. 2014, Jiang et al. 2016, Yang et al. 2017).
- grow it yourself (GIY) – Ecovative are selling bags of dehydrated mycelium inoculated substrate. Dry conditions reserve the mycelium in hibernation and it is reactivated by adding water and flour to the bags. The reactivated mycelium can be placed in custom shaped forms prepared by the user (Ecovative GIY, 2018).

This study aims to characterize the compressive resistance of mycelium composite prepared in laboratory conditions and compare it with low density particleboards.

MATERIALS

Two sets of samples were made (Figure 1). The first set consisted of low density mycelium boards (MBs) consisting of mycelium of fungus *Trametes versicolor*, and the second set consisted of low density particleboards (PBs). The applied substrates consisted of industrially produces spruce wood particles intended for the core layer in the production of OSB boards. The portion and size distribution of particles in substrates can be found in Table 1.

Further, the MBs substrate contained wheat flour in the amount of 4 % wt. (weight of flour per weight of wood particles), mycelium of *Trametes versicolor* on malt agar plates (170 cm^2 for 100 g of the substrate) and demineralised water (30 ml for 100 g of the substrate).

The special PBs with low density were prepared from same particles with average moisture content 3.7 ± 0.17%, urea-formaldehyde glue (solids 66%) in amount of 8% wt. (absolute dry weight of UF per weight of absolute dry particles), ammonium nitrate as hardener in amount of 4% wt. (weight of hardener per used weight of UF), and paraffin emulsion in amount of 1% wt. (absolute dry weight of paraffin emulsion per weight absolute dry particles).

Table 1. Overview of wood substrate – the size and portion distribution of wood particles.

Spruce wood particles	The portion of particles fractions in substrate [%]								
Size [mm]	20	11.2	4	1.6	1.25	0.8	0.5	0.25	fines
Low density MBs	6.03	13.59	40.68	24.95	4.84	6.11	2.84	0.60	0.36
Low density PBs	0.94	10.5	54.7	24.42	3.72	3.84	1.32	0.4	0.16

Note: Substrate weight (before the test analyse of the portion and size distribution of particles) = 100 g.

METHODS OF FABRICATION OF THE BOARDS

Fabrication of the MBs (Figure 2A) – The substrate was sterilized by placing it in autoclave at temperature of 121°C and pressure 1.25 kPa for 60 minutes. After cooling, the substrate was mixed with flour, water and fungal mycelium. The substrate was then placed into Petri dishes with diameter 180 mm and the nominal thickness of 30 mm. The Petri dishes were closed and then placed in a climatic camber. The samples were allowed to grow in dark conditions, during 21 days, at the constant temperature of 30 ± 2°C. After the growth period, the samples were placed inside a room and subsequently in an oven at 60°C and dried for 8 hours. 5 low density MBs were prepared in total.

Fabrication of the PBs (Figure 2B) – The 1-layer PBs with the area size of 250 mm × 180 mm and the nominal thickness of 25.0 mm were prepared in laboratory conditions. The application of a mixture of urea-formaldehyde glue, hardener and paraffin emulsion on wood chipped particles was performed in a laboratory rotary mixing device. The wood particles were coated with glues, then loaded into a pre-pressing form, and finally pressed in a laboratory press. The pressing process was performed in accordance with the three stages pressing diagram (Figure 1) at the maximum specific pressure of 4.5 MPa, a temperature of 210°C, and a pressing factor of 12 s. In total, 6 low densities PBs were prepared.

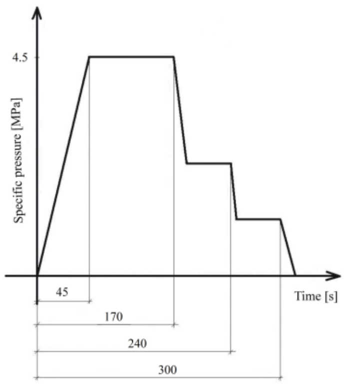


Figure 1. Three stages of pressing diagram

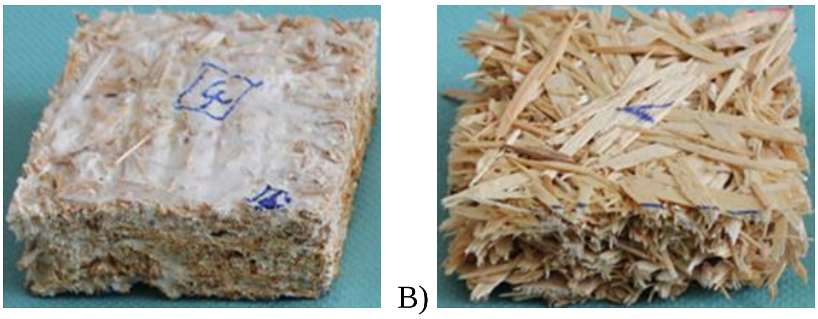
A) B)


Figure 2. Mycelium board (A) and low density particle board (B)

COMPRESSIVE TESTS

Measuring compressive properties of the prepared boards was done in accordance with the standard ASTM C 165-07. Strength was defined as the stress at a 20% deformation. Both groups of samples were tested using a FPZ 100/1 machine at a 9.41 mm.min^{-1} load speed. The compressive resistance was calculated as follows:

$$S = W/A \tag{1}$$

where:

S – compressive resistance [Pa],
W – load at 20% deformation [N],
A – average original area of tested sample.

RESULTS

Figure 3 reported compression curves in which the load increased exponentially with deformation. The initial slope was evidently higher for PBs than MBs. An actual point of stress at a 20% deformation was reached in a 5–6 mm displacement equal to 20% of the depth of the test specimens.

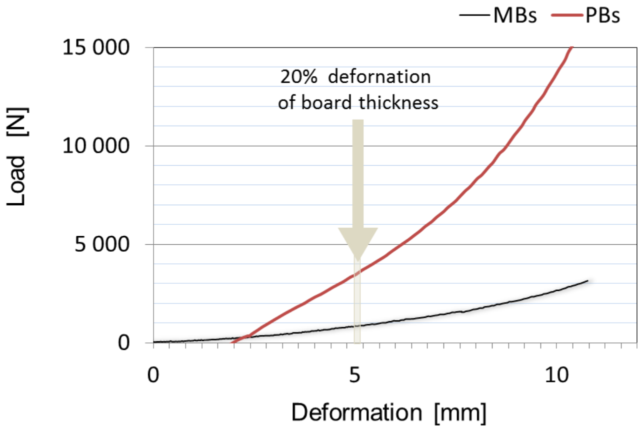


Figure 3. Load-deformation diagram for a mycelium board (MBs) and a low density particle board (PBs)

The average compressive strength of MBs samples at a 20% deformation was 23.95 kPa, which was approximately eight times lower than that of the PBs samples, and approximately four times lower than that of expanded polystyrene (Table 2).

Table 2: A comparison of low density structural materials

Material	Density [kg/m^3]	Compressive resistance at a 20% deformation [kPa]
Low density MBs	103.0 (0.01)	23.95 (6.79)
Low density PBs	189.2 (3.68)	199.0 (73.98)
Expanded polystyrene	13.50 – 18.00	96.90 (Vnuk 2017)

Note: Standard deviation is in parentheses.

The compressive strength of mycelium composites varies greatly depending on their constituents. Two mycelium composites using the genus Ganoderma achieved very different compressive strength results based on differing substrate materials. Cotton plant-based mycelium composites achieved compressive strengths between 1 and 72 kPa (Holt et al. 2012), while a red oak-based mycelium composite achieved 490 kPa (Travaglini et al. 2013), which was almost seven times stronger.

According to Travaglini et al. (2013), the mycelium foam had a compressive strength almost three times the tensile strength. The low density and specific compressive strength make it a sustainable option as the core of sandwich materials. Travaglini et al. (2013) also suggests using it in combination with fibre-reinforced top layers made of eco resins in order to further enhance the ecological message.

Another work related to fungal composites (Travaglini et al. 2014) used woodchips as a filler material. This produced composites with flexural strengths of up to 490 kPa and flexural moduli of up to 1300 kPa. While these studies capture the impact of filler materials on the mechanical properties, they do not highlight the impact of the fungal structure on the properties.

CONCLUSSION

- Though the observed compressive strength is rather low compared with other materials (PBs, expanded polystyrene), it should be noted that MBs are fully bio-based, formaldehyde free, compostable and fully degradable. There is a potential for improvement of properties by densification of a mat during preparation of MBs.

- Bond strength of mycelial growth would thus appear to be equivalent to that achievable using synthetic resin, since the substitution of these bonding media is the primary difference between mycelium boards and traditional particleboard.

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