REPORT OF RESEARCH RESULTS

(a) Title: The sustainable development of the bio-based fire-retardant guide post from mycelium-based composite using spent coffee grounds mixed with agro-waste and recycled paper

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(c) Summary: Include the outline and conclusions of the research

Mycelium biocomposites (MBCs) offer a sustainable, zero-waste alternative for non-structural construction materials. Here, we report the potential of using high-content spent coffee ground (SCG) mixed with rice husks (RH) and pure recycled paper (RP) as substrates for MBC growth, specifically for road guidepost materials. Three compositions of MBCs were fabricated: (MBC/RP, MBC/SCG50-RH50, MBC/SCG80-RH20). Compression test, water absorption, and fire resistance performance were characterized alongside microstructural analyses via SEM and X-ray μCT. Experimental results disclosed that substrate morphology critically governs MBC performance. MBC/RP achieved the highest compressive strength (1.67 MPa) at high strain 0.58 mm/mm and an excellent V-0 fire rating due to dense mycelial entanglement with fibrous substrate and protective char layer formation. Conversely, MBC/SCG-RH groups exhibited lower strength (0.25–0.46 MPa) and fire resistance. Nevertheless, MBC/SCG80-RH20 achieved the highest stiffness (2.41 MPa) and exhibited brittle behavior, linked to SCG-RH particle interlocking that created a closed-pore structure up to 61.61% and significantly lower water uptake (130%) than open-pored MBC/RP (272% water uptake and 52.87% porosity). Accordingly, MBC/SCG-RH groups are better suited for biodegradable packaging while MBC/RP was strong potential of MBC/RP as a material for road guideposts. Despite susceptible to high moisture, MBC/RP maintained structural integrity in dry environments, demonstrating a functional lifespan exceeding three months. The practical feasibility was validated by successfully fabricating an initial 1:4 scale MBC/RP road guidepost prototype. These findings confirm the potential of tailoring waste resources to meet mechanical, fire performance, and degradability for non-load-bearing outdoor applications.

(d) Aim of Research

The goal of this project is to investigate the feasibility of MBC to be used as road guidepost or road barrier materials. Therefore, this study is primarily clarified the properties of MBC made from various substrates. The aims of the research are as follows,

(i) To investigate the physical and mechanical properties of MBC deriving from high-content spent coffee grounds compared with fire-retardant materials made from bioplastics, MBCs made from the other substrates, and conventional non-structural construction materials

(ii) To investigate the end-of-life disposal of MBC deriving from high-content spent coffee grounds via the compostability in soil

(e) Method of Research & Progression

1. Mycelium biocomposite (MBC) fabrication process

The total dry mass of the mixed SCG/RH substrate for each inoculation bag was 250 g. Three substrate formulae were prepared based on the SCG:RH weight ratios; 50:50, 70:60, and 80:20.

Distilled water, 1.5 times the dry weight of the substrate, was added and thoroughly mixed to achieved the required moisture content. Shredded recycled office paper (RP) was obtained from offices in Thai-Nichi Institute of Technology. The dry weight of the RP substrate per one inoculation bag was 250 g, with distilled water added at 1.5 times the dry weight. Both substrate types (SCG/RH mix and RP) were sealed in inoculation bags and sterilized in an autoclave (DGS-280B Portable Pressure Steam Sterilizer, China) at 125°C for 40 min. The substrates were inoculated with 10 wt% of *Pleurotus ostreatus* mycelium spawn (GMP standard number 2507-2559, LLLBiotech Co.Ltd., Saraburi Province, Thailand). The inoculated substrates were incubated for 14 days in a mini-smart farm at 25-30°C and 75-85% RH. Once the mycelium had fully colonized the substrate, the composite was broken up into small particles and then molded into the desired shape. The molded samples were further incubated in the mini-smart farm for an additional 14-20 days. The samples were demolded and their growth was deactivated by drying them in a hot-air oven (Binder redline RF 115 redline, Germany) at 110°C for 8 h.

2. Dry density of MBCs

The MBC dry density (ρ) was determined after it was dried in a hot-air oven using the following equation:

$$\rho = \frac{m_{dry}}{V_{dry}} \quad (1)$$

where m_{dry} and V_{dry} are mass of MBC sample [kg] and its volume [m^3] after drying, respectively.

3. Morphological observations

The surface morphology of the MBC specimens was initially observed using a digital optical microscope (BM-DM61, Ningbo Barride Optics Co., Ltd., China). The internal morphology of samples was observed by Scanning Electron Microscopy (SEM) (JEOL JSM7800F, JOEL Ltd., Japan), following the compression test to primarily investigate the mycelium bonding with the different substrates. SEM observations visualize the 3D network of mycelial fibers binding with the particulate substrates and the specimen surface. The internal pore structure was quantitatively analyzed using X-ray micro-computed tomography (X-ray μCT). The voxel size was set to 32.70 μm. The μCT system was used to reconstruct the 3D images, which were then imported into ImageJ software for porosity analysis.

4. Mechanical properties

The uniaxial compression test was conducted according to ASTM D1621-00 using a universal testing machine (AGS-X, Shimadzu, Japan). The nominal dimensions of MBC samples for the compression test were 70×70×40 mm. The test was performed under displacement control at a crosshead speed of 2.5 mm/min with six replicates per formulation. Each specimen was compressed up to 15 mm of displacement, or until specimen fracture. The compressive strength was recorded.

5. Fire-retardant properties evaluation (Modified UL-94 criterion)

Specimens were fabricated with dimensions of 125×13×10 mm following the dimensional requirements of the UL-94 standard. Five initial specimens were prepared for each composite batch. A commercial gas lighter (Tailong TL-26241, China) was employed as the ignition source. All available parameters were strictly controlled during the test, and the resulting fire characteristics were classified visually and based on time measurements according to the UL-94 criteria

6. Environmental exposure test and MBC guidepost prototype

Since the primary target applications of this study is the development of MBC for road safety materials or general construction materials, the technical specifications for road safety materials from the Department of Highways (DOH) and Department of Rural Roads, Thailand, were used as references. The test was conducted outdoors in Bangkok from September to December. This period was divided into two distinct phases to capture seasonal variation: the rainy season (September to late October, characterized by frequent rainfall) and the dry season (late October to December). The weight of each MBC sample was recorded weekly throughout the duration of the test.

(f) Results of Research

1. Dry density analysis

The dry density of the composites after fungal deactivation was measured as 257.36 ± 25.30 kg/m^3 for MBC/RP, 164.35 ± 18.26 kg/m^3 for MBC/SCG50-RH50, and 206.57 ± 7.24 kg/m^3 for MBC/SCG80-RH20. MBC/RP exhibited the highest density, which was 1.25 times higher density than the average density of the MBC/SCG-RH groups. Dry density generally reflects the compactness of the solid materials (mycelium + substrate) within both the particulate (MBC/SCG-RH) and fibrous (MBC/RP) composites. Hence, higher density correlates to lower overall porosity of MBC.

2. Mechanical properties

The stress-strain curves (Fig.1) reveal non-linear elastic behavior across all MBC composites, which is characteristic of highly porous materials. The MBC/RP composite achieved the highest maximum compressive strength, reaching 1.62 MPa at 0.58 mm/mm strain. This strength is substantially three to four times higher than the MBC/SCG-RH composites in this study (MBC/SCG80-RH20 (0.46 MPa), MBC/SCG50-RH50 (0.25 MPa)) and significantly exceeds values for previous woodchip-based MBCs. The maximum compressive strength achieved by MBC/RP (1.62 MPa) is significantly lower than that of commercial biocomposites (e.g. hemp/epoxy, jute/epoxy (20–80 MPa) and WPCs (30–70 MPa). Besides, the MBC/RP achieved this strength at very low density (257.36 kg/m^3) through an extremely low-energy bio-fabrication process. This disparity highlights the sustainability advantages of MBCs over biocomposites and WPCs, which require high energy and pressure during manufacturing.

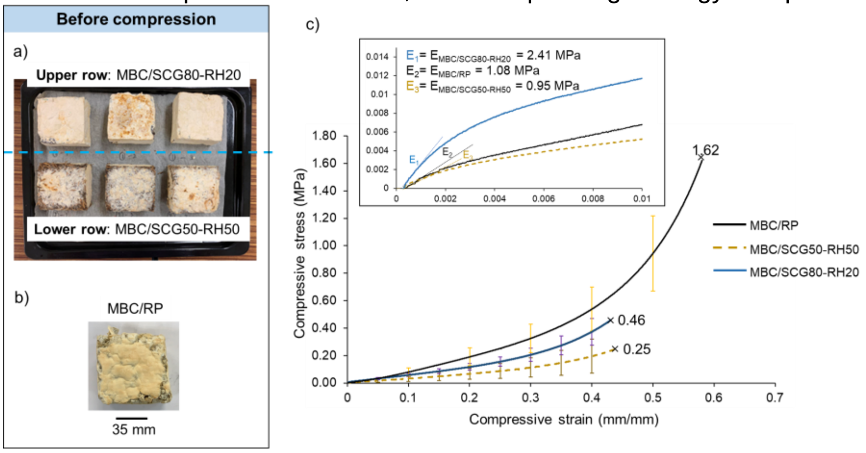

Fig.1 Before compression photographs of (a) MBC/SCG-RH and (b) MBC/RP composites. Average stress-strain curves of MBC composite in this study

3. Fire resistance performance

Both the MBC/RP and MBC/SCG70-RH60 specimens successfully passed the HB test, self-extinguishing after the 30-s ignition period. These specimens were then subjected to VB test. The MBC/SCG70-RH60 composites (Fig.2) demonstrated good self-extinguishing characteristics, with minimal flame time (lasting only 1–2 s) between the five on/off ignition sets and no material dripping. Nevertheless, due to inconsistent performance—with one replicate burning up entirely in the third test set, and a second re-test also showed similar characteristics—the MBC/SCG70-RH60 could not be formally classified according to the UL-94 standard. The MBC/RP composite demonstrated superior performance (Fig.2c). It exhibited immediate self-extinguishing upon removal of the ignition source during every on/off fire-ignition set, with no continuous flame and no dripping due to melting. After the last ignition set, the specimen immediately self-extinguished. The afterglow time was short, 20 s, resulting in the final char length less than 25 mm (Fig.2c). Based on UL-94 criteria, the MBC/RP composite is classified as V-0.

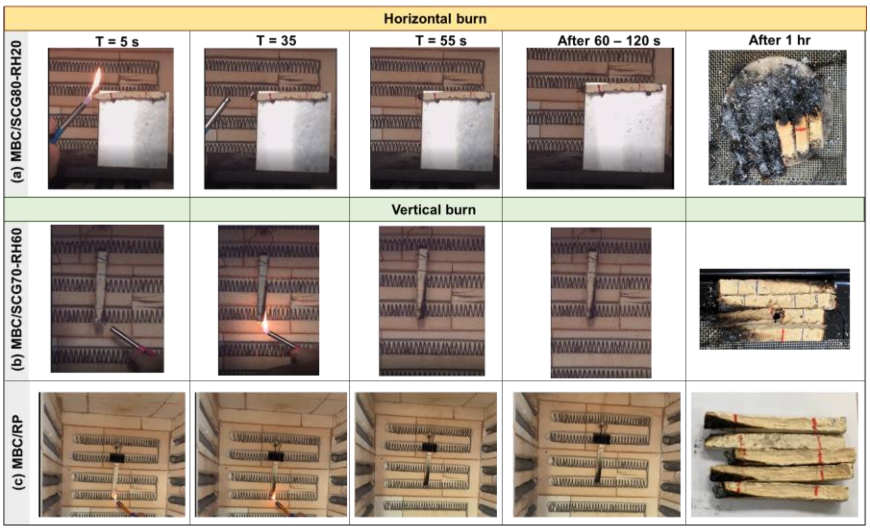

Fig.2 Fire resistance characteristics of (a) MBC/SCG80-RH20, (b) MBC-SCG70-RH60, and MBC/RP

4. **MBC road guidepost prototype and environmental exposure test**

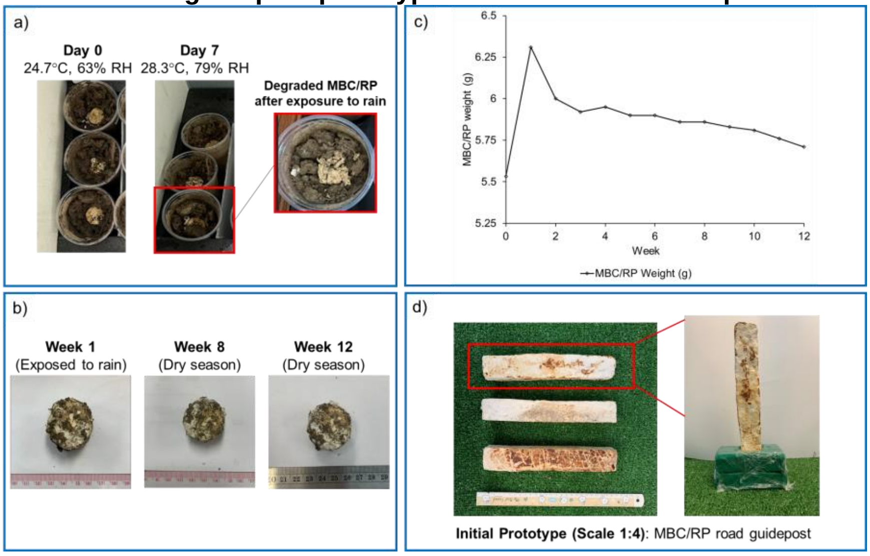

Fig.3 Environmental exposure test and MBC/RP road guidepost prototype scale 1:4

Accordingly, the MBC/RP composite was the only material in this study that exhibited compressive strength higher than 1 MPa and achieved an excellent fire resistance rating (V-0), closely aligning with the requirements set by Department of Rural Roads, Thailand. Despite its relatively higher water absorption, MBC/RP was therefore selected as the sole potential candidate worth evaluating for long-term durability in the environmental exposure test. Fig.3(a) suggests that the limitation for MBC/RP as a road guidepost material is its susceptibility to moisture ingress in high-humidity regions. However, the MBC/RP demonstrated the ability to withstand and remain dimensionally stable for more than three months during dry season in Thailand (Fig.3(b)). The performance of MBC/RP in this study confirms its potential for use as a guidepost in regions of Thailand with infrequent rain, provided the application demands a lifespan exceeding three months. For universal application, surface coating will be necessary to overcome the susceptibility of MBC/RP to water absorption. Furthermore, the successful fabrication of a scale 1:4 MBC/RP road guidepost prototype (Fig.3(d)) provides the tangible demonstration and feasibility of MBC/RP for practical application. While this confirms the structural potential, future work must focus on evaluating the impact test under real-world conditions.

(g) Future Areas to Take Note of, and Going Forward

Future work should prioritize two main directions:
(1) Developing effective surface coating strategies to mitigate the high water absorption of MBC/RP, enabling its universal deployment in high-humidity outdoor environments.
(2) Enhancing the structural integrity of the MBC/SCG-RH blend through material or processing modifications to broaden its application potential beyond packaging.

(h) Means of Official Announcement of Research Results

a. International Journal: Composite Part C: Open Access (Q1, IF 7.0)
P. Sratong-on, S. Prapan, W. Chaithanee, K. Puttawongsakul, S. Joy-A-Ka, Mycelium biocomposites from spent coffee grounds, rice husk, and recycled paper for temporary eco-road guideposts: Microstructure-property relationships, fire resistance, and outdoor durability, Composites Part C: Open Access,19 (2026), 100699. https://doi.org/10.1016/j.jcomc.2026.100699
b. International Conference: STT51 (peer reviewed, abstract only)
P. Sratong-on, K. Puttawongsakul, N. Kanthawee, S. Joy-A-Ka, S. Prapan, Spent coffee ground/rice husk and recycled paper-based mycelium biocomposites for sustainable road guideposts, The 51th International Congress on Science, Technology and Technology-Based Innovation (STT51), Thailand, 2025, pp.196
c. “Silver medal” in Energy Materials and Environment field of Graduated Students in I-NEW GEN AWARD 2026, National Research Council of Thailand, Bitec Bangna, 5-9 Jan. 2026
Project title: MushPot: Sustainable Biocomposite – Low Carbon Biodegradable Alternatives to Foam and Plastics