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Guest Articles

3D Printed Eco-Friendly Acoustic Panels

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Introduction

Sound pollution, one of the current environmental issues, arises from myriad sources ranging from traffic, construction, and industrial activities to aircraft/spacecraft, loud music, and other household appliances. As per the World Health Organization (WHO) standards, sound waves above 65 decibels (dB) are considered as polluted noise. Researchers have utilized many types of acoustic materials such as mineral wool, synthetic fibres, and polymer foams, especially in the building and construction industry. However, these conventional materials could act as health hazards to humans and their solid waste contributed to environmental pollution (Qui et al. 2018). Herein we report the preparation and acoustic performance of two novel composites using pineapple leaf fibres (PALF) and water hyacinth fibres (WHF) with polylactic acid (PLA).

Over the past few years, PALFs and WHFs have been studied on sound adsorption applications due to their unique characteristics such as high cellulose fiber

content, porosity, readily availability, low-cost, and environment-benignity (Putra et al. 2018; Sukhawipat et al. 2022). Polylactic acids (PLAs), also known as synthetic biopolymers or bioplastics, have recently been considered for fabricating thermoplastic filaments in 3D printing due to their low melting range, high strength, low thermal expansion, and better layer-adhesion (Yang et al 2014; Appuhamillage et al. 2018).

To the best of our knowledge, this work represents the first mechanically robust, 3D-printed acoustic panels that achieve the maximum sound absorption coefficient (α -max) > 0.5 with relatively low fiber loading. Most importantly, these panels are effective within the high-frequency sound range of 2,000 to 20,000 Hz. Our innovative approach paves the way for future developments of low-cost acoustic devices as a solution against noise pollution associated with high frequencies. Moreover, the current study provides a sustainable solution for mitigating the notorious aquatic weed, *Eichhornia crassipes* (water hyacinth).

Materials and Methods

PLA (Luminy LX175) in fine resin pellet form (melt flow index-MFI at 190 °C/2.16 kg) was received from Natur Tec Lanka (Pvt) Ltd, Sapugaskanda, Sri Lanka. Water hyacinth (WH) plants were obtained from Wedaru Lake in Kurunegala, Sri Lanka. Pineapple plant leaves were collected from a pineapple fruit farm at Avissawella, Sri Lanka. Sodium hydroxide (NaOH) and sodium hypochlorite (NaOCl) powders were purchased from Glorchem Enterprises, Colombo 11, Sri Lanka.

Extraction of fibers

The fresh WH stems were first separated from the roots and other parts of the plant. Then, the WH stems were cleaned to remove dust and ash and immersed in water for 5 days to soak. Separated WHFs were then sun-dried for another 15 days to remove water and then mechanically crushed. On the other hand, the collected PALs were fed into a decorticator/defibering machine, and PALFs were extracted directly. Finally, these PALFs were sun-dried for 8 hours and mechanically crushed using a cutting mill (SM300-Rostfrei).

Chemical treatments

In order to remove the hemicellulose, lignin, proteins, pigments, other impurities, and amorphous fractions, both alkaline (using 5 wt. % of NaOH solution) and bleach (using 1.5 wt.% of NaOCl solution) treatments were performed on WHFs and PALFs. Removal of impurities upon treatments reduces the diameter of fibers having high surface area pore networks. Oscillating air molecules of incident sound waves loss their momentum via friction inside these high surface area pores, thereby improving acoustic properties (Samaei et al. 2020).

Preparation of composites

Above chemically treated fibers were further dried in oven at 105 °C until a constant weight and then subjected to mechanical crushing to yield powders of 250 microns particle size. These finely ground WHFs and PALFs were separately subjected to homogenous mechanical mixing with PLA, according to Table 1.

Table 1. Composition of the composites in wt.%.

Material	PLA (wt.%)	WHF (wt.%)	PALF (wt.%)
Control (neat PLA)	100	0	0
1WHF/PLA	99	1	0
5WHF/PLA	95	5	0
7WHF/PLA	93	7	0
10WHF/PLA	90	10	0
1PALF/PLA	99	0	1
5PALF/PLA	95	0	5
7PALF/PLA	93	0	7
10PALF/PLA	90	0	10

After that, each fine mixture was separately introduced into a mould (200 mm (length) × 200 mm (width) × 1 mm (thickness)) of a heat-press machine ZLCB5-2, and the composites were prepared at 200 °C for 4 min under 2 MPa pressure. After cooling for 15 min the composites were removed from the mould.

Thermal characterization

As-prepared composites and neat PLA (the control) were subjected to TGA analysis using the TG analyzer (TGA 5500- Discovery TA) at 30-700 °C under a nitrogen atmosphere and at a 10 °C/min heating rate. DSC analysis was also performed using a DSC Q100-TA instrument in the 30-300 °C temperature range at a heating and cooling rate of 10 °C/min.

Fourier transform infrared (FTIR) spectroscopic analysis

FTIR analysis was performed using an FTIR-6100-JASCO spectrometer in the 4000 - 500 cm⁻¹ range at a resolution of 2 cm⁻¹ and 16 scans. Transmission mode was used with JASCO's exclusive Spectra Manager TM II cross-platform software. All FTIR samples were prepared using KBr pellets.

Testing physico-mechanical properties

Density, hardness, tensile, and impact strength tests were also performed following the relevant standard test methods.

Acoustic property measurements

The sound absorption coefficient (α) was calculated for the composites in the 500 -5,000 Hz frequency range using a standard impedance tube, following the ISO 10534-2 standards ("ISO 10534-2 (1998-11)"). Disc-shaped samples (panels) with 5 cm diameter and 1 mm thickness were used for testing. Neat PLA was used as the control. Triplicate readings were taken from each sample for a particular sound frequency (Hz). Average α values have been plotted vs. sound frequency (Hz).

3D printing

First, the 3D printable filaments were prepared using a laboratory developed technique as described in Wijekoon et al. 2024. The composites 1WHF/PLA, 1PALF/PLA, and neat PLA, the control, were 3D printed into disc-shaped panels of 5 cm diameter and 1 mm thickness using a 3D printer (Creality-Ender 3). All the 3D printing parameters were in accordance with those reported in Wijekoon et al. 2024.

Post-printed testings

Acoustic property, tensile strength, and toughness measurements were also taken for the as-printed panels. SEM analysis was also performed to detect the distribution of pores.

Results and Discussion

In this section, results of 3D printing, post-printed acoustic, tensile, toughness, and SEM analysis are discussed. Figure 1 denotes the successfully 3D printed acoustic panels.

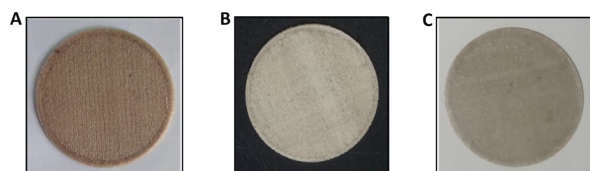


Figure 1: 3D-printed acoustic panel of 1 WHF/PLA (A), 1 PALF/PLA (B), and neat PLA (C). Adapted from Wijekoon et al. 2024.

Figure 2 illustrates the resulting absorption coefficient (α) values against sound frequency for the 3D printed panels. Both WHF/PLA and PALF/PLA composites

demonstrated α -Max > 0.5 in the high sound range (2,000-20,000 Hz) with only 1 wt% cellulosic fiber loading. Contrary to previous studies reported in the literature, our results show a significant potential for improving the acoustic properties of 3D-printed composites with minimal fiber content. Moreover, the porosity of the composites is only contributed by cellulose fibers, and there are no effects of drilling methods and 3D printing on the porosity.

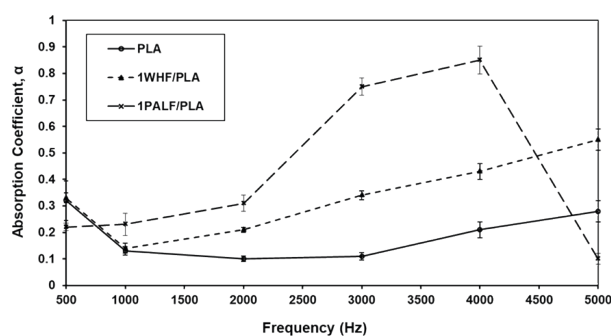


Figure 2: Variation of α with increasing sound frequency (Hz) for the 3D-printed acoustic panels of 1 WHF/PLA, 1 PALF/PLA, and neat PLA (sample thickness is 1 mm). t-Tests demonstrate a statistical significance of $p < 0.05$ for the α values of 1 WHF/PLA vs. PLA and those of 1 PALF/PLA vs. PLA, obtained at 2000, 3000, 4000, and 5000 Hz. Adapted from Wijekoon et al. 2024.

Figure 3 demonstrates the post-printed tensile and toughness properties of the panels.

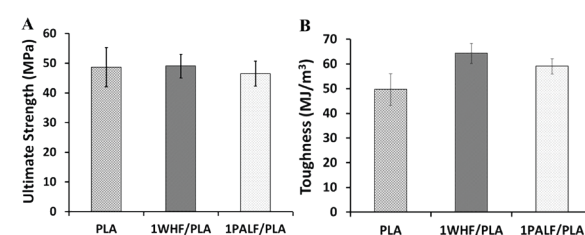


Figure 3: Tensile strength of 3D-printed ASTM D638-type V standard tensile specimens of 3D printed panels (A). t-Tests demonstrate no statistical significance of $p > 0.05$ for these measurements. Toughness values of such 3D-printed panels (B). t-Tests demonstrate a statistical significance of $p < 0.05$ for the toughness values of 1 WHF/PLA vs. PLA and those of 1 PALF/PLA vs. PLA. Adapted from Wijekoon et al. 2024.

Figure 4 denotes the surface and cross-sectional SEM images obtained for the 3D printed panels.

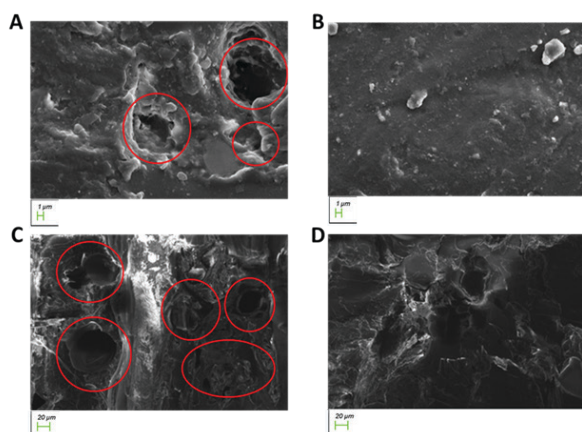


Figure 4: Scanning Electron Microscopic (SEM) images of the 3D-printed 1 WHF/PLA panel and neat PLA. Surface SEM images of 1 WHF/PLA (A) and neat PLA (B) obtained using 5000 × magnification. Cross-sectional SEM images of 1 WHF/PLA (C) and neat PLA (D) obtained using 500 × magnification. Pores have been circled in red. Adapted from Wijekoon et al. 2024.

Conclusions and future work

In conclusion, the work reported here introduced the easy preparation of composites with natural cellulosic fibers of WH and PAL with PLA. For the first time, the FFF-based AM of these materials has yielded mechanically robust and sustainable composite acoustic panels that showed the best performance within the high-frequency sound range at a low fiber loading of 1 wt %. The 3D-printed 1 WHF/PLA panel achieved α -max of 0.55 at 5,000 Hz, while the printed 1 PALF/PLA panel showed its best acoustic performance of α -max of 0.83 at 4,000 Hz. Moreover, the resulting tensile strength of the 3D-printed panels is approximately three-fold higher than the non-3D-printed versions and significantly higher than many commercial acoustic absorbers. These low-cost and environmentally friendly 3D-printed composite panels can be used as green engineering materials to construct walls and ceilings to negate high-frequency noises. Importantly, this study also provides a sustainable

solution for aquatic weeds, such as water hyacinth (WH), by utilizing them to produce sound absorbers.

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