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Technical note

Acoustic and thermal properties of a cellulose nonwoven natural fabric (barkcloth)

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ABSTRACT

The desire to mitigate climate change due to greenhouse gas emissions has led to the exploration of plant fibers as alternative materials for various industrial applications, sound absorption inclusive. In this investigation, sound absorption properties of *Antiaris toxicaria* barkcloth, and the thermal insulation properties of the barkcloth epoxy laminar composites were characterized. Theoretical sound absorption models were utilized to validate the experimental data and the empirical models were in agreement with experimental data. The lowest thermal conductivity was achieved by the *Antiaris toxicaria* epoxy composites.

1. Introduction

Rapid industrialization and growth of metropolis come with challenges such as noise pollution. According to the new World Health Organization report, traffic related noise accounts for over one million healthy years of life lost annually to ill health, disability, or early death. Furthermore, among the environmental factors contributing to disease in Europe, environmental noise leads to a disease burden that is only second in magnitude to that from air pollution. Noise pollution causes or contributes to not only annoyance and sleep disturbance, but also heart attacks, learning disabilities, and tinnitus [1].

The use of sound absorbing materials is the most effective means used in buildings, automotive, aerospace, and other transport vehicles to abate noise and vibrations through the absorption of the acoustic energy of the acoustic wave as it propagates through the sound absorber [2]. Synthetic materials such as polymer foams, glass fiber, polyester, mineral wool are the leading sound absorption or noise reduction materials used. However, the biggest drawback is that most of the raw materials sources are from fossil fuels.

In order to create a new class of materials, sustainable, renewable material sources are being explored as a consequence of the Kyoto protocol on global climate change [3]. A comparison based on the Ecoinvent database [4] between the environmental impacts of some traditional and natural sound insulation materials from cradle to gate shows that vegetable fibers need less energy for production and contribute minimum greenhouse gas emissions.

The acoustic properties of jute felt and rubber composites were investigated by Fatima and Mohanty [5]. The addition of rubber was found to reduce the noise reduction coefficient whereas treatment with alkali had no significant change in the sound absorption coefficient. Na and Cho [6] investigated the sound absorption and viscoelastic property of automotive nonwovens and the effect of treatment with plasma. It was observed that jute nonwoven of 5.62 mm thickness used in car headliner felts had good sound absorption at higher frequencies (3000–5000 Hz) whereas treatment with plasma led to the reduction of the sound absorption property of jute nonwovens. A blend of jute-polypropylene nonwoven performed well as a sound absorber and was found to be suitable materials for car flow coverings [7,8]. Yang and Li [9] showed that Jute, Ramie and Flax nonwovens of thickness, 40 mm exhibited better sound absorption performance in comparison to synthetic fibers. Arenga pinnata bast fiber samples of thickness, 40 mm exhibited the sound absorption coefficient within the range of 0.75–0.90 with respect to the frequency 2000–5000 Hz [10].

Zulkifh et al. [11] studied the acoustic properties of multilayer coir fiber panels and found out that the developed panels had a sound absorption coefficient of 0.70–0.80 in the frequency range of 1000–1800 Hz. Fouladi et al. [12] showed that fresh coir fiber

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felt of thickness, 20 mm exhibits an average sound absorption coefficient of 0.8 above the frequency of 1360 Hz. Increasing the thickness improved the sound absorption in lower frequencies, having the same average sound absorption at a frequency greater than 578 Hz and with the thickness of 45 mm. The addition of recycled tyre rubber to coir reinforced polyurethane resin composites produced a positive effect of the composite boards under investigation [13]. Xiang et al. [14] showed that kapok fiber has excellent acoustical damping performance due to its natural hollow structure, and the sound absorption coefficients of kapok fibrous assemblies were significantly affected by the bulk density, thickness and arrangement of kapok fibers but less dependent on the fiber length. Compared with assemblies of commercial glass wool and de-greasing cotton fibers, the kapok fiber assemblies with the same thickness but much smaller bulk density may have similar sound absorption coefficients.

The sound absorption coefficient of rice straw-wood particle composite boards was higher than wood-based materials in the frequency range of 500–8000 Hz [15]. Generally, because agricultural waste such as rice straw and sawdust have low porosity after compaction with binders, the sound absorption properties are lower compared to nonwovens [16]. Doost-hoseini et al. [17] investigated the sound absorption coefficients of insulating boards made of bagasse with the thickness of 12 mm. Urea–formaldehyde and melamine–urea–formaldehyde were used to produce homogeneous as well as three-layered insulating boards with three densities of 0.3, 0.4, and 0.5 g/cubic cm. The obtained results indicated that resin-type affected the sound absorption coefficients. The maximum absorption coefficient was found at 2000 Hz of frequency (in the multi-layered board of 0.50 g/cm^3 of density, produced with urea–formaldehyde resin), and the minimum was observed at 500 Hz (homogeneous board of 0.50 g/cm^3 produced with urea–formaldehyde resin). Ersoy and Küçük [18] showed that tea leaf fiber can be used as a sound absorption material, the results showed a beyond average absorption coefficient with a backing of cotton.

Incorporation of an air gap between sound absorption materials has a positive effect on the absorption behavior of the material assemblies [19,20].

In this investigation, sound absorption and thermal insulation properties of barkcloth, a nonwoven fabric from *Antiaris toxicaria* were characterized. Theoretical sound absorption models available in literature were utilized to validate the experimental data.

Table 1
Overview of barkcloth material properties [22–24].

Property	Unit	Value
Physical and mechanical properties		
Areal weight	g/m^2	123
Average thickness	mm	1.12
Fabric strength		
Fiber direction	N	101.7
Transverse	N	23.5
Chemical composition		
α-Cellulose	%	68.69
Hemicellulose	%	15.07
Lignin	%	15.24
Thermo-physiological properties		
Thermal conductivity coefficient	W/m K	0.0357
Thermal absorptivity	W s$^{1/2}$/m^2 K	0.197
Thermal resistance	m^2 K/W	81.4
Thermal diffusivity	m^2 s^{-1}	0.034
Peak heat flow density	[W m^2] × 10^{-3}	0.234
Relative water vapor permeability	%	66
Evaporation resistance	Pa m^2	4.4

2. Materials and methods

Barkcloth from *Ficus natalensis* and *Antiaris toxicaria* fabrics was extracted using the method described by Rwawiire et al. [21]. Table 1 shows an overview of physical, chemical and mechanical properties of Barkcloth. Using vaccum assisted resin transfer molding, synthetic Epoxy resin LG285 and amine hardener HG 285 supplied by GRM systems, Czech Republic was utilized in the production of composite panels.

2.1. Acoustic properties

The acoustic properties of barkcloth were investigated using a type 4206 Brüel&Kjær impedance tube according to ISO10534-2 standard using two quarter-inch condenser microphones type 4187 (Fig. 1A). The principle of measurement works in such a way that the sound source is generated by a loudspeaker at the end of the impedance tube; the sound waves are transmitted to the surface of the material sample (Fig. 1B). The tube measures the physical sound absorption coefficient (the fraction of acoustic energy not reflected by the material surface), which is a quotient of acoustic energy absorbed by the material to the energy of the incident wave.

The material samples with a diameter of 29 mm; thickness ranging from 1 to 1.4 mm were studied in the frequency range of 500–6400 Hz. The airflow resistivity was measured utilizing the air resistance meter and the value of airflow resistivity was calculated utilizing the equation below:

$$\sigma = \frac{\Delta P}{Ud} \quad (1)$$

where ΔP is the set pressure difference between the surfaces; U is the air flow velocity and d is the thickness of the sample.

2.2. Thermal properties

Alambeta thermal conductivity measuring device [22] which measures the thermal conductivity of specimens of up to 8 mm was used under room temperature. The composites (Fig. 2) were ground using sandpaper so as to achieve a uniform smooth surface for thermal conductivity tests. Chemical silicon paste was used to condition the samples, thus serving a dual purpose of a lubricant to prevent damage to the device's measuring probes and the fastening of the device heating plate to the samples.

Fig. 1. Sound absorption measurement procedure: (A) Brüel&Kjær impedance tube set up; (B) sample of the barkcloth layers studied.