INVESTIGATION OF SOUND ABSORPTION PROPERTIES OF BARK CLOTH NONWOVEN FABRIC AND COMPOSITES

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Abstract:

The quest for sound-absorbing materials that are not only environmentally friendly, but also sustainable is the foremost reason for natural fibre-acoustic materials. Bark cloth is a natural non-woven fabric that is largely produced from Ficus trees. An exploratory investigation of bark cloth a non-woven material and its reinforcement in epoxy polymer composites has been fabricated and investigated for the sound absorption properties so as to find the most suitable applications and also to see whether bark cloth can be used in some applications in place of man-made fibres. Three types of material species were investigated with their respective composites. The fibre morphology showed bark cloth to be a porous fabric that showed promising sound absorption properties at higher frequencies. The sound absorption results of four-layer material selections of Ficus natalensis, Ficus brachypoda and Antiaris toxicaria bark cloth showed sound absorption coefficient of 0.7; 0.71 and 0.91 at $f > 6400$ Hz, respectively. The bark cloth reinforced laminar epoxy composites had reduced sound absorption coefficients, which ranged from 0.1 to 0.35, which was attributed to decreased porosity and vibration in the bark cloth fibre network.

Keywords:

Bark cloth, Acoustic properties, Epoxy, Composites

1. Introduction

Increased industrialisation and growth of the metropolis world over leads to noise pollution from various sources. According to a 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 in western Europe. Among 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 acoustic absorbing materials is the most effective means used in buildings, automotive, aerospace and other transport vehicles. Synthetic materials such as polymer foams, glass fibre, 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 and renewable material sources are being explored as a consequence of the Kyoto protocol on global climate change [2].

The ecological 'green' image of cellulose fibres and considerable mechanical properties fit for secondary structures coupled with low health risk is the leading argument for innovation and development of products, which are biodegradable and can be

applied to the automotive industries, building and construction [3–5]. Plant-based fibres like flax, hemp; nettle and kenaf, which were once used to provide textile fibre in the western world, have attracted renewed interest this time for industrial composite applications [6–8].

According to the report [9] on Global Natural Fibre Composites Market 2014–2019: Trends, Forecast and Opportunity Analysis, showed that by 2016, the natural fibre composites market is expected to be worth US 531.2 million with an expected annual growth rate of 11% for the next 5 years [10]. Currently, natural fibres account to over 14% share of reinforcement materials; however, the share is projected to rise to 28% by 2020, amounting to about 830,000 tons of natural fibres [11]. This, therefore, shows the importance of study of acoustic properties of natural fibre-reinforced composites since their utilisation, especially in the automotive sector, is on the rise.

Liu *et al.* [12] utilised wood fibre and rice straw for the development of thermal and acoustic insulation panels with thickness ranging from 50–150 mm. The sound absorption coefficient of the developed biocomposites was above 0.8 for a wide frequency range 250–7000 Hz. The acoustic properties of jute felts and rubber composites were investigated by Fatima and Mohanty [13]. Addition of rubber was found to reduce the noise-reduction coefficient whereas treatment with alkali had no significant change on the sound absorption coefficient.

Zulkhifh *et al.* [14] studied the acoustic properties of multilayer coir fibres, 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.

Yang *et al.* [15] investigated the acoustic properties in the range of 500–8000 Hz of rice straw-wood particle composite boards and found that the sound absorption coefficient was higher than wood-based materials. Sound-absorbing materials are porous in nature and therefore, the sound absorption coefficient is proportional to their thickness and inversely proportional to the resistance of air through them [16].

Various cellulose fibres have been investigated for acoustic properties such as coir [16–19], sugarcane bagasse [20], tea leaf fibre [21], rice straw, wood particle composite [22], kapok [23]; therefore, cellulose fibres, which are usually discarded, are being explored for value-added products, sound absorption panels inclusive.

According to United Nations Educational, Scientific and Cultural Organization (UNESCO), Bark cloth, a non-woven fabric has been in production in Uganda for over six centuries; however, there's a limited study of the non-woven felt, which is produced through a series of pummelling processes. That notwithstanding, in 2005, UNESCO proclaimed it as a 'Masterpiece of the Oral and Intangible Heritage of Humanity' [24].

Non-woven felts have been investigated as sound absorption materials by various researchers [25–27]. Therefore, in this study, an exploratory investigation of the sound absorption properties of the non-woven fabric from the inner bark of mutuba trees (*Ficus natalensis*) is characterised. In terms of green credentials and sustainability, the trees grow naturally in Central Uganda and do not need fertilisers. The fabric layers were studied and their performance in sound absorption was evaluated. Epoxy polymer was used as a binder of the bark cloth plies and the developed composites were also studied for their sound absorption properties.

2. Experimental

2.1. Materials

Bark cloth (Figure 1) was extracted from *F. natalensis*, *Ficus brachypoda* and *Antiaris toxicaria* using the method described by Rwawiire & Tomkova [24]. Epoxy resin LG285 and hardener HG285 supplied by GRM systems, Czech Republic, was used in composite sample fabrication.

2.2. Composite fabrication

Epoxy resin LG285 and Hardener HG285 supplied by GRM systems, Czech Republic was used in composite sample fabrication. The resin to hardener ratio was maintained at 100:40 as per the manufacturer's directives; Vacuum Assisted Resin Transfer Molding (VARTM) was used to prepare the Bark Cloth Fibre Reinforced Composites (BFRC) (Figure 2). Four bark cloth plies were used in the manufacture of the composites, resin was infused into the fibre performs using vacuum pressure. The composite was left to cure at room temperature for 72 hours.

2.3. Characterisation methods

Morphology

The microstructures of the fabrics were investigated using a Vegas-Tescan scanning electron microscope (SEM) with accelerating voltage of 20 KV.

Acoustic properties

The acoustic properties of the bark cloth and its composite were investigated using a type 4206 Brüel & Kjær impedance tube according to ISO10534-2 standard using two quarter-inch condenser microphones type 4187 (Figure 3).

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

Figure 1: Bark cloth samples

Figure 2. Bark cloth ply samples being infused with resin using VARTM

Figure 3: Brüel & Kjær impedance tube

surface of the material sample (Figure 3). When a sound wave strikes the bark cloth materials, it would cause vibration of the particles causing friction, thereby generating heat, which is absorbed by the bark cloth and some sound energy is reflected and picked up by sensors.

Bark cloth being a non-woven material, its ability to absorb sound is influenced by the fibre network that dissipate the sound energy and also absorb the heat generated as the sound energy is being dissipated.

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 had a diameter of 29 mm and were studied in the frequency range of 500–6400 Hz.

The composite and multilayer samples were cut to the above diameter according to the standard. The sound absorption coefficient was measured for composites, single layer, double layers, triple layers and finally, quadruple layers. Since the fabricated BFRC specimens had four plies, acoustic characteristics had to be characterised for the respective bark cloth layers and their effects on sound absorption.

Table 1: Sample thickness.

No.	Sample	Thickness [mm]
1	A. toxicaria	
	First layer	1.07
	Second layer	1.25
	Third layer	0.98
	Fourth layer	1.33
	Total thickness	4.63
	Antiaris BFRC	2.50
2	F. brachypoda	
	First layer	1.33
	Second layer	1.12
	Third layer	1.23
	Fourth layer	1.38
	Total thickness	5.06
	F. brachypoda BFRC	2.12
3	F. natalensis	
	First layer	1.02
	Second layer	1.42
	Third layer	0.72
	Fourth layer	1.03
	Total thickness	4.19
	F. natalensis BFRC	2.93

Table 1 shows the thickness of the non-woven felts used.

3. Results and discussion

Morphology

The fabric fibre morphologies are shown in Figures 4 and 5. It is observed that the bark cloth fabrics are composed of a network of fibres that are embedded with woody substances. Bark cloth obtained from *Ficus* species has more plant and woody material on the fibre structure. This material acts as a binder that binds the bark cloth microfibres together. The transverse section of the cloth shows that the microfibres are polygonal in shape, however, encased in the woody material (Figure 5). The air gaps that exist between the fibre enclosure and the woody material dictate the sound absorption properties of the fabrics.

The ability of a non-woven material to act as an efficient sound absorption material is influenced by the fibre network and the morphology of the respective fibres. It is observed that bark cloth is made up of various microfibres of diameter ranging from 20 to 30µm in diameter (Figure 5). It is these fibres that play a major role in absorbing the incident sound energy as well as absorbing the resulting heat from dissipation of sound energy.

Figure 4: Fibre morphology of (A) *F. natalensis* (B) *A. toxicaria*

Figure 5: Fibre morphology of (C) *Ficus brachypoda* (D) Transverse sectional view

Acoustic properties

The acoustic properties of one-layer fabrics of the three species are shown in Figure 6. The sound absorption properties for one-layer samples of the bark cloth fabrics with the thickness of about 1.14 mm are similar for each kind of samples. The sound absorption coefficient generally increases with increase of frequency.

The one-layer bark cloth fabrics between the frequency range of 1000–3200 Hz have an average sound absorption coefficient of 0.05, whereas beyond 5000 Hz, the fabric's sound absorption becomes 0.1 and the properties favourable to *Antiaris* and *F. natalensis* bark cloth.

The effect of layer thickness was investigated and Figure 7 shows the sound absorption properties of *F. natalensis* fabrics with one, two, three and four layers. The sound absorption properties increase with increase in sample thickness. All the fabrics studied had a gradual increase of sound absorption coefficient. *F. natalensis*' four-layer fabrics had a sound absorption coefficient of 0.7 at 6400 Hz.

The two-layer samples showed a sound absorption coefficient of 0.1 at 3000 Hz; 0.15 at 4000 Hz; 0.2 at 5000 Hz and 0.25 at 6000 Hz. The addition of another layer almost doubled the sound absorption performance of the fabrics as can be seen in the behaviour of the samples with three layers.

F. brachypoda fabrics showed similar behaviour as *F. natalensis* fabrics (Figure 8). It is observed that the three-layer fabrics of *F. natalensis* were better than for *F. brachypoda* as can be seen from the graphs. *F. brachypoda* had a sound-absorption coefficient of 0.71 at 6400 Hz.

The sound absorption performance of *A. toxicaria* fabrics is presented in Figure 9. It is observed that the performance of the fabrics at 6400 Hz was overall best having a sound absorption coefficient of 0.92 compared to the average of 0.7 obtained from the *Ficus* bark cloth species. Krucinska *et al.* [27] showed that cotton/PLA composites of 5.8 mm thickness with microfibres had a sound absorption coefficient of 0.93 at 6400 Hz. The bark cloth fabrics showed an irregular dependence of sound absorption coefficient of like other non-wovens over a wide range of frequency, this behaviour was also confirmed elsewhere [26].

The comparable excellent acoustic properties of bark cloth fabrics at high frequencies are attributed to fibre entanglement in the fabrics and porosity. *Antiaris* bark cloth with four layers showed better sound absorption properties compared to other types of bark cloth. The investigated sound absorption properties showed that *A. toxicaria* bark cloth has higher sound absorption properties at higher frequencies. Increasing the bark cloth, fibre layers showed a positive trend towards sound absorption coefficient; thus, giving a prediction of multilayer

Figure 6: One-layer bark cloth sound absorption properties.

Figure 7: *F. natalensis* bark cloth sound absorption properties

Figure 8: *F. brachypoda* bark cloth sound absorption properties

Figure 9: *Antiaris toxicaria* bark cloth sound absorption properties

products of *Antiaris* bark cloth the potential to provide positive results even at low-frequency ranges.

The increase of the bark cloth layers increases the contact surface area for the incident sound waves; this, therefore, increases more absorption of heat due to the heat dissipation and also leads to less reflection of the waves.

Jiang *et al.* [25] showed that the base layer of cotton with thickness of 35 mm had a sound absorption coefficient of approximately 0.92, whereas the composite of the cotton base layer and glass layer of 3 mm having a total thickness of 38 mm had a sound absorption coefficient of 0.95. In comparison to the four-layer bark cloth, non-woven fabrics that had the highest thickness of 5.06 mm, bark cloth performance was exceptional since *Antiaris* bark cloth with thickness of 4.06 mm had a sound absorption coefficient of 0.91 at 6400 Hz.

The sound absorption properties were investigated further whereby the four layers of bark cloth were utilised in the production of composites. Two surfaces were investigated in order to understand whether the perturbations on the composite surface have an effect on the sound absorption properties. The molded composites' sound absorption properties of smooth surfaces are shown in Figure 10.

The *Ficus* bark cloth composites have a sound absorption coefficient below 0.1 for the frequency of up to 3700 Hz and thereafter, *F. brachypoda* sound absorption properties increased with increase in frequency reaching its peak of 0.35 at 6400 Hz. *Antiaris* BFRC sound absorption, increased for frequency of 5000 Hz and then decreased, showing the same trend with *F. natalensis* BFRC.

The effect of surface perturbations on the sound absorption properties is shown in Figure 11, which showed a marked increase in the sound absorption properties. It is observed that the perturbations increased the sound absorption properties of *Antiaris* BFRC having an average sound absorption

coefficient of 0.15 between frequency ranges of 2500–5000 Hz.

The low performance of the composites with sound absorption is due to the effective packing of the method used for production of the composites. VARTM is an efficient method of production of composites with less voids and with smooth, even packing that showed insignificant sound absorption properties compared to the fabrics that were used to reinforce the epoxy resin. This is due to the fact when a sound wave strikes a porous fibre network like bark cloth; the sound waves cause vibration in the fibre network. The vibration causes minute heat build-up in the fibres due to friction. Therefore, a good absorbing material absorbs the energy of the sound waves and less heat is generated. However, in composites, the compaction of the bark cloth non-woven felt results in reduced porosity, thus increasing flow resistivity and reduced vibration of the fibre network, therefore a reduced sound absorption coefficient [28].

3. CONCLUSION

In this investigation, for the first time, bark cloth has been introduced as a potential sound absorption material.

The results show that bark cloth non-woven fabric has good sound absorption properties and can be used as an alternative replacement for the synthetic commercial fibres, which are widely used in the industry.

The investigated sound absorption properties showed that *A. toxicaria* bark cloth has higher sound absorption properties at higher frequencies. Increasing the bark cloth fibre layers showed a positive trend towards sound absorption coefficient, thus giving a prediction of multilayer products of *Antiaris* bark cloth the potential to provide positive results even at low frequency ranges.

Figure 10: Bark cloth epoxy laminar composite sound absorption properties with smooth surfaces

Figure 11: Bark cloth epoxy laminar composite sound absorption properties with surface perturbations

Production of composites showed that there is a decrease in the sound absorption properties due to the decrease in the porosity and thickness due to the compression of the fabrics under pressure, therefore reducing the vibration of the fibres since they are bonded in the matrix that increases stiffness and thereafter decreasing the overall acoustic properties of the bark cloth reinforced composites.

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