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Leila Sheldrick,
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Novel sound absorption materials produced from air laid non-woven feather fibres

Elena Dieckmann [a,c,d], **Stephen Dance** [b], **Leila Sheldrick** [a], **Christopher Cheeseman** [d,*]

[a] *Dyson School of Design Engineering, Imperial College London, SW7 1NA London, UK*

[b] *The Acoustics Group, London South Bank University, Borough Road, London SE1 0AA, UK*

[c] *Aeropowder Ltd, London, UK*

[d] *Department of Civil and Environmental Engineering, Imperial College London, London SW7 2BU, UK*

[*] Corresponding author.

E-mail address: c.cheeseman@imperial.ac.uk (C. Cheeseman).

Abstract

This research has investigated the use of feather fibres to produce sound absorption materials as an alternative to the oil derived synthetic plastics that currently dominate the sound absorption materials market. In this paper we show that clean and disinfected waste feathers from the poultry industry can be processed into fibres and air laid using commercial pilot plant facilities to form non-woven feather fibre composite mats. By varying the composition and processing conditions, materials with a range of different properties such as thickness and density were produced. The sound absorption coefficients of samples was determined using the impedance tube method (BS EN ISO 10534-2: 1998), using normal incidence sound between 80 and 1,600 Hz. The data reported shows that air laid non-woven feather fibre mats have improved sound absorption coefficients compared to other natural materials used for sound absorption for a given thickness, particularly in the problematic low frequency range between 250 to 800 Hz. We conclude that air laid non-woven feather fibres have high potential to be used as effective and sustainable sound absorption materials in aerospace, automotive, buildings, infrastructure and other applications where sound absorption is required.

Keywords: Acoustics, Civil engineering, Materials science

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1. Introduction

The unique properties of feathers means that they have potential to be engineered into new high-performance materials. Feathers consist predominantly of the protein keratin, but have a complex structure consisting of a hollow shaft (quill) and rachis, with vanes consisting of barbs and barbules, as shown in Fig. 1 [1]. As a result, feathers have high tensile strength and toughness, extremely lightweight and excellent thermal insulating properties. Feathers are also reported to have unusual acoustic properties because the shaft and barbs inhibit sound transmission by absorbing and very effectively dissipating sound waves [2].

Feathers are also a significant waste, particularly from the chicken processing industry. In the EU annual poultry feather production is ∼3.1 million tonnes per annum [3]. Applications for waste feathers are limited compared to other natural fibres such as wool, hemp and sisal. Feathers are used for filling duvets, garments and upholstery, but this requires specific types of down feathers and these applications could only ever use a very small percentage of the total feathers generated. Waste poultry feathers produced in the UK are processed by autoclaving to form feather-meal, a low-value, low-grade, protein rich animal feed currently exported to Eastern Europe and Russia [4].

Lightweight sound absorption materials are critically important in aerospace and automotive applications, in some specific civil infrastructure developments where sound transmission is an issue, and in buildings [5]. Foamed plastics are normally

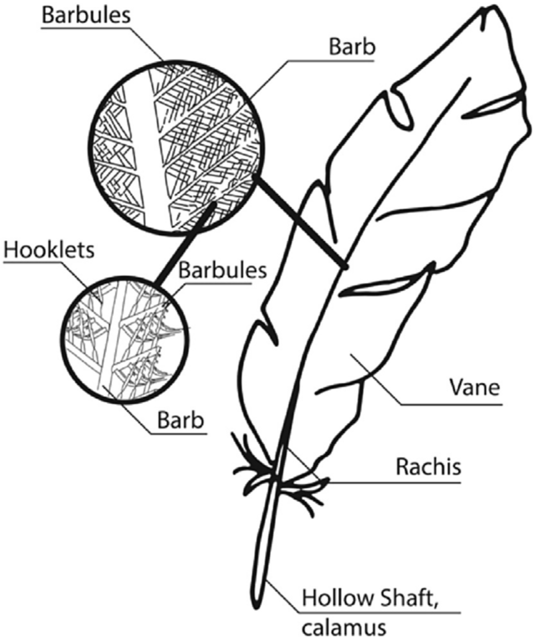

Fig. 1. Feather structure consisting of a hollow shaft (Quill) and rachis, with the vane consisting of barbs and barbules.

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used for sound absorption, but there is a need to develop alternative more sustainable materials. The acoustic properties of a range of natural and recycled materials have recently been reviewed, although this did not include data for feathers [6]. In addition the sound absorption properties of feather mats formed using the specific materials processing technology we have used in this study have not previously been reported.

The air laid manufacturing process enables short fibres to be formed into a range of different non-woven mat products with different densities and thickness using minimal addition of binder materials. A schematic diagram of the pilot scale air laid process used to produce non-woven air laid mat samples from feather fibres is shown in Fig. 2. The mixed fibres fall under gravity to form a loose bed of fibres on a conveyor, the speed of which determines the bed thickness. As the fibre bed is formed it is continually moving to a zone where it is simultaneously heated and pressed between two moving belts to produce the air laid non-woven mat product. Varying the spacing between the moving belts controls the density and thickness of the mat samples produced. This type of processing is typically used to form synthetic fibres into a range of consumer products including wipes, thermal insulation materials and personal hygiene products.

In this research we apply air laid manufacturing to feather fibres to form new non-woven feather fibre mats. The sound absorption properties of the feather fibre mats has been investigated using an impedance tube. This allows the determination of a range of different sound adsorption parameters. The performance of the feather fibre mats have been compared to mats made from cellulose fibre and mineral fibre that are currently used for sound absorption. We also compare our data to literature data for other types of natural fibre mats. To our knowledge this is the first time that air laid non-woven feather fibre mats with a range of densities and thickness

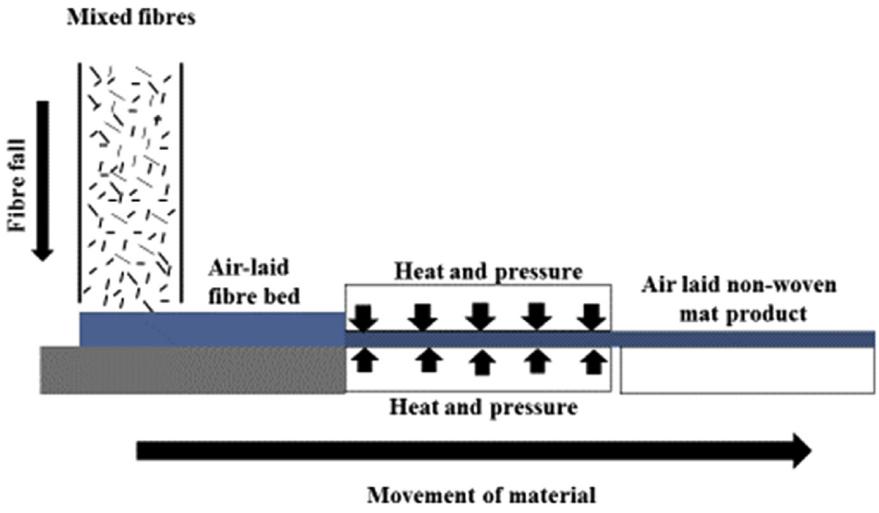

Fig. 2. Schematic diagram showing the air laid process used to form non-woven feather fibre composites.

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have been produced and the sound absorption characteristics reported and compared to other materials.

2. Materials and methods

Waste chicken feathers obtained from a major UK poultry facility processing producing approximately 160 tonnes of wet soiled by-product feathers a week were thoroughly washed, disinfected and dried. They were then granulated (Rapid 2040 granulator, Sweden) to produce feather fibres. The feather fibres were characterised by optical microscopy using image analysis (Keyence VHX-5000).

Air laid samples contained between 10 and 30 wt.% of short (6 mm) bi-component fibre made from polyethylene (PE) with a polyester (PET) core (LMF-Bico, Fipatec). These form a coherent non-woven feather fibre mat when the outer surface of the fibre softens during the heating stage in the air laid process, bonding the feather fibres into a coherent isotropic mat. Samples were also produced by blending feather fibres with 30 wt.% cotton fibres. A typical air laid non-woven feather fibre composite mat produced is shown in Fig. 3.

Table 1 shows the composition, thickness, densities and mass of the air laid non-woven feather fibre mats produced in pilot scale trials. The internal microstructure of selected samples were examined using scanning electron microscopy (SEM, Phenom Pro X) on gold-coated samples to ensure electrical conductivity.

Sound absorption coefficients were determined using an impedance tube (BSWA Tech Ltd Model SW422 [7]) with a tube width of 100 mm, following the method described in BS EN ISO 10534-2: 1998 [8]. Air temperature, pressure and humidity were measured and were in accordance to BS EN ISO 9613-1:1993 [9]. The sound absorption coefficients were determined for normal incidence over a frequency range from 80 and 1,800 Hz. For each material three samples were tested and each sample was tested three times and the average determined. The temperature during sound testing was 21.7 °C and the relative humidity was 47%.

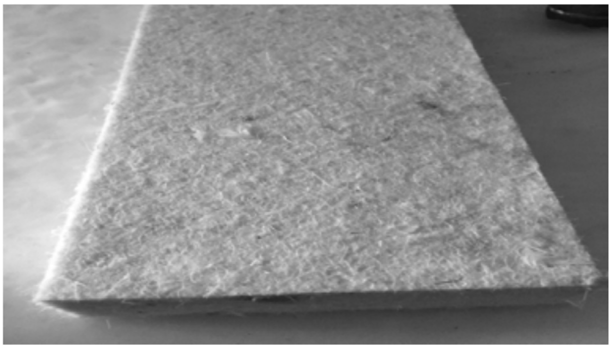

Fig. 3. Typical air laid non-woven feather fibre composite material.

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Table 1. Composition the non-woven feather fibre composite mats manufactured in pilot plant trials and tested in this research. The table also shows the density, thickness and mass per unit area of the different samples tested, including the cellulose and mineral wool fibre mats used in this study.

Sample	**Composition**			**Density Kg·m^{-3}**	**Thickness mm**	**Mass g·m^{-2}**
	Feather fibre content	**Bi-component fibre content**	**Cotton fibre content**			
1	90	10	0	30	30	900
2	85	15	0	50	75	3750
3	70	30	0	100	25	2500
4	60	10	30	32	50	1600
5	45	25	30	32	75	2400
6	45	25	30	32	15	480
7. Cellulose fibre mat				56	50	2800
8. Mineral wool				41	50	2040

The sound absorption coefficients of the feather fibre mats were compared to commercial sound absorption products based on cellulose and mineral fibres determined using the same testing protocol [10]. Sound absorption data was compared to literature data available on other natural fibres [11].

3. Results

Fig. 4 shows the appearance of the feather fibres after milling. The average length of granulated feather fibres determined by image analysis was 0.9 mm with a typical fibre width of 12 μm. Feather fibres had a high level of curl and were extensively fibrillated. The microstructure of an air laid non-woven feather fibre mat is shown in Fig. 5. The relatively loose packed and open structure of the feather fibres is evident, with a supporting network formed by the bi-component polymer fibres, which appear as much smoother than the feather fibres.

Sound adsorption characterisation data is given in Table 2. A number of metrics have been used including the overall weighted sound absorption coefficient (SAC) [12], the noise reduction coefficient (NRC) [13], the sound absorption average (SAA) [14] and the sound absorber classification [12]. The weighted sound absorption coefficient (α_w) as defined in BS EN ISO 11654:1997 requires measurements at 250–2000 Hz [12]. The noise reduction coefficient is an arithmetic average of the 250–2000 Hz octave band absorption coefficients as given in ASTM 923-09a [13]. This standard was recently updated in ASTM 923-17 [14] and this gives the sound absorption average which is the arithmetic average of the absorption coefficients between 200 and 2500 Hz, in 1/3 octave bands.

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Fig. 4. Optical microscope image of feather fibres produced by milling washed and dried waste poultry feathers.

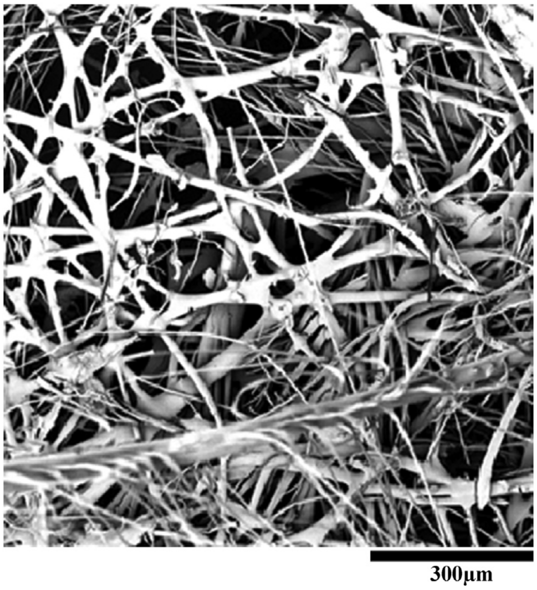

Fig. 5. SEM image showing the microstructure of the air laid non-woven feather fibre composite.

An absorption coefficient of 0 indicates no sound absorption, while a coefficient of 1 indicates the maximum possible sound absorption. The ratings calculated assume that the normal angle of incidence sound absorption coefficient, as measured in an impedance tube, is an accurate indication to the random incidence sound absorption coefficient, as the random incidence value is always higher than the normal incidence coefficient [15]. It was also assumed for these porous materials the absorption coefficients for frequencies higher than 1800 Hz are stable [10, 11].

Fig. 6 shows the sound absorption performance for the feather fibre mat samples 1, 2 and 3 over a range 80−1600 Hz in 1/3 octave bands. These samples vary in bi-co

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Table 2. Extrapolated weighted sound absorption coefficients, sound absorber classification, noise reduction coefficient, and sound absorption averages for all the samples tested in this research.

Sample	Weighted sound absorption coefficient α_w	Sound absorber classification	Noise reduction coefficient	Sound absorption average
1	0.40	D	0.55	0.55
2	0.60	C	0.60	0.58
3	0.40	D	0.45	0.44
4	0.60	C	0.70	0.68
5	0.80	B	0.80	0.78
6	0.25	E	0.30	0.30
7. Cellulose fibre mat	0.50	D	0.65	0.63
8. Mineral wool mat	0.50	D	0.65	0.66

component addition, density and thickness and show a range of acoustic performance. The sound absorption properties of the specimens tested tend to be high at frequencies above 800 Hz, where the absorption coefficients typically exceed 0.70. However, the sound adsorption coefficients at frequencies below 200 Hz are low. It is evident that mass per unit area and thickness significantly influence sound absorption and sample 2 gives good low frequency sound absorption.

The results in Fig. 7 are for samples containing 30% cotton fibres that have the same density but different thickness and therefore different mass per unit area. Sound absorption is highly dependent on sample thickness as seen by comparing the data for samples 5 (75 mm) and 6 (15 mm). The 75 mm thick sample 5 has high sound

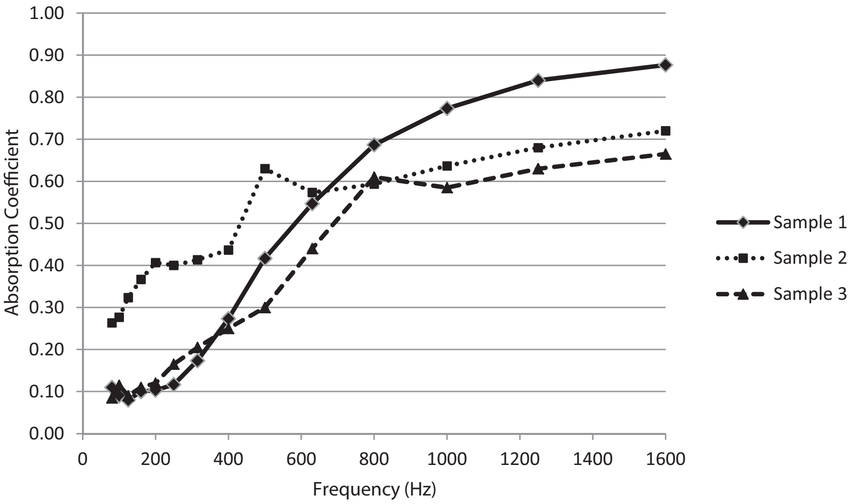

Fig. 6. Sound absorption coefficient data for samples 1, 2 and 3 which had different feather fibre content, bi-component fibre content, density and thickness.

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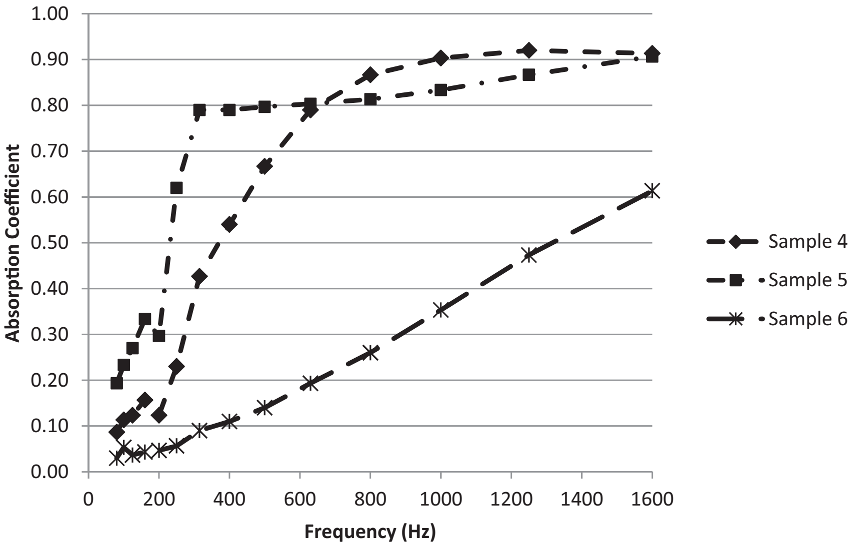

Fig. 7. Sound absorption coefficient data for samples 4, 5 and 6 which had 30 wt.% cotton fibre addition, constant density (32 kg m^{-3}) and varying thickness.

absorption coefficient down to 315 Hz, while the 15 mm thick sample (sample 6) has the lowest sound absorption coefficient of the materials tested. Sample 5 performs particularly well above 250 Hz. Conversely, the thinner lighter materials did not perform as well, providing similar performance but at one octave high frequency for each halving of the mass and/or thickness.

Fig. 8 shows the results of mat samples with the same thickness and compares feather fibre sample 4 with commercially available cellulose fibre and the mineral wool mats. All three samples show very similar performance across the frequency range of interest. However, at the critical lower sound frequencies between 250 and 800 Hz the feather fibre mat (sample 4) shows improved absorption.

The frequency data can be used to give the sound absorber classification for each mat and this is included in Table 2. This confirms that the best performing sound absorption was achieved by the feather fibre sample 5 which had the greatest thickness (75 mm) and the highest density (2400 g/m^2). The key observation is that for a given thickness but at lower density, feather fibre mats out-perform commercially available cellulose fibre and mineral fibre mats, indicating the excellent sound absorption properties of feather fibres by comparison. The improved sound adsorption classification of feather fibres sample 4 is due to the improved sound absorption at frequencies between 250 and 800 Hz.

4. Discussion

The results show that 50 mm thick feather fibre mat with density of only 1,600 g cm^{-3} (sample 4) has improved sound absorbing properties compared to cellulose

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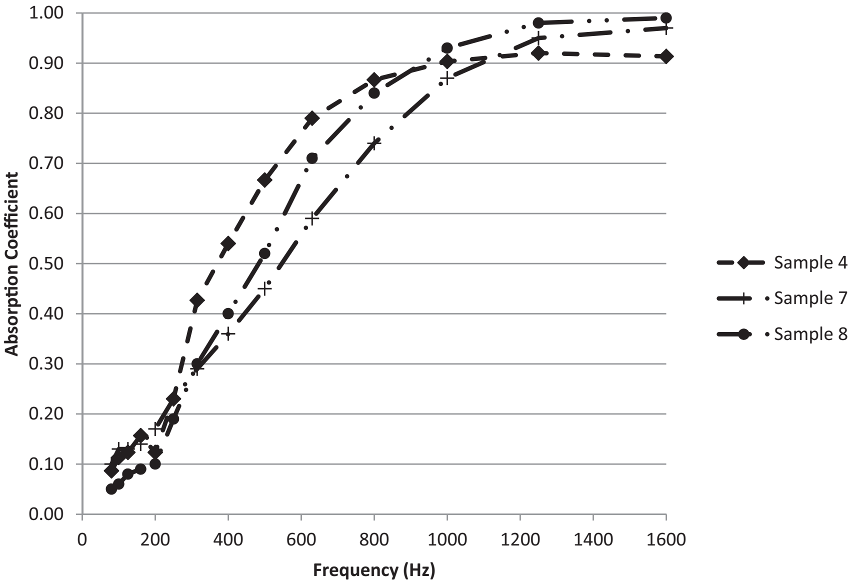

Fig. 8. Sound absorption coefficients for feather fibre mat (sample 4) compared to commercial material samples with the same thickness (50 mm). Sample 7 is the cellulose fibre mat and sample 8 is the mineral wool mat. The data shows the improved performance of the feather fibre mat (sample 4), particularly between 250 and 800 Hz.

fibre mats with a density of 2,800 g cm^{-3}. The cellulose fibre mat has a D classification as a sound insulator, while feather fibre sample 4 has a C classification. The extrapolated weighted sound absorption coefficient was 0.5 for the cellulose fibre mat, compared to 0.6 for sample 4. The fact that the feather fibre mat had significantly lower density than the cellulose fibre mat indicates the improved acoustic absorbing properties of feather fibres compared to cellulose fibres, and highlights the likely benefits of further exploration with the use of feather fibres within sound absorbing materials.

Further evidence of the good sound absorption of feather mats is given by comparing the noise reduction coefficients obtained using similar tests for a number of different types of natural fibres [11]. This is shown in Table 3. The noise reduction coefficient (NRC) has been replaced by the sound absorption average and this alternative rating is included in Table 2. The alternative natural fibres tested give similar ratings to the feather fibre sample 4, with an NRC = 0.7 [11]. However, sample 4 has lower density (32 kg m^{-3} compared to 100 kg m^{-3} and 40 kg m^{-3}) and is thinner (50 mm compared to 60 mm and 60 mm) than the kenaf fibre and sheep wool fibre samples. The results for sample 4 indicate that feather fibres out-perform both wood and coconut fibres for sound absorption and this highlights the potential for manufacturing improved sustainable sound absorption products using feather fibres. The air laid non-woven feather fibre composites tested have excellent sound absorption properties across a range of frequencies. The sound absorption properties are highly

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Table 3. Material characteristics and extrapolated noise reduction coefficients for sustainable materials.

Sample	Density ($kg \cdot m^3$)	Thickness (mm)	Noise reduction coefficient
Feather fibre mat sample 4	32	50	0.70
Kenaf[a]	100	60	0.70
Wood fibre[a]	100	60	0.60
Sheep wool[a]	40	60	0.70
Coconut[a]	60	50	0.50
Cellulose fibre mat	56	50	0.65
Mineral wool mat	41	50	0.65

[a] Data taken from reference [11].

dependent on sample thickness, whereas specific variations in the relative amount of bi-component fibre and the inclusion of cotton fibres in the mix have less impact on performance.

Sound absorption in the sample mats tested is controlled by dissipation of acoustic sound energy through absorption and reflection, and this occurs through complex interactions between sound waves and the feather fibre material. The increased sound absorption associated with non-woven feather fibre compared to cellulose fibres and mineral fibres is related to the inherent structure of the feather and the properties of keratin. This provides a microstructure and surface interactions that cause high sound energy dissipation and absorption. The research highlights the potential for using for non-woven feather fibres mats as lightweight sound insulation products with potential for use in a range of applications.

The global market for sound absorption products is expected to reach US$ 21.57 billion by 2025, driven by population growth and industrialization in emerging countries such as Brazil, China, India, South Africa, Mexico and Russia [16]. There is a need to develop residential, commercial and industrial infrastructure with improved sound properties and this is supported in many regions by government initiatives to improve sound absorption performance. Feathers from poultry processing are available in all countries as a waste material, although up until now the development of acoustic products using feather fibres has been largely ignored. As part of a circular economy, there are significant opportunities to process waste feathers into new products. However, in order to explore the development of fully circular materials for these air laid mats, biodegradable binder materials are needed to replace PET and PE. Feathers therefore represent a valuable sustainable alternative biomaterial, and this research demonstrates their potential to be exploited as a resource in cost effective, high performance, sustainable sound absorption products.

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5. Conclusion

Non-woven air laid feather fibre mats have the potential to be used as sustainable, lightweight natural materials for sound absorption. For a given thicknesses the sound absorption of feather fibre mats compares favourably with commercially available sound absorption materials based on cellulose and mineral wool fibres and literature data for other natural fibre boards. Feather fibre mats have low density and improved sound absorption at low frequencies between 250 and 800 Hz which can be particularly problematic. Increasing the thickness improves the sound absorption classification. High performance at low frequencies and light weight indicate potential for sound absorbing feather fibre mats to be used in automotive, aerospace, commercial interiors and construction. This represents a viable high-performance application of a problematic and high-volume waste that is readily available in many countries. Further characterisation is needed to compare the relative environmental and social impacts of feather based products against commercially available sound absorption materials.

Declarations

Author contribution statement

Elena Dieckmann: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Stephen Dance: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Leila Sheldrick: Wrote the paper.

Christopher Cheeseman: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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