

Acoustic Absorption of Hemp Walls with Ground Granulated Blast Slag

Oliver Kinnane, Aidan Reilly, John Grimes, Sara Pavia, Rosanne Walker

Abstract—Unwanted sound reflection can create acoustic discomfort and lead to problems of speech comprehensibility. Contemporary building techniques enable highly finished internal walls resulting in sound reflective surfaces. In contrast, sustainable construction materials using natural and vegetal materials, are often more porous and absorptive. Hemp shiv is used as an aggregate and when mixed with lime binder creates a low-embodied-energy concrete. Cement replacements such as ground granulated blast slag (GGBS), a byproduct of other industrial processes, are viewed as more sustainable alternatives to high-embodied-energy cement. Hemp concretes exhibit good hygrothermal performance. This has focused much research attention on them as natural and sustainable low-energy alternatives to standard concretes. A less explored benefit is the acoustic absorption capability of hemp-based concretes. This work investigates hemp-lime-GGBS concrete specifically, and shows that it exhibits high levels of sound absorption.

Keywords—Hemp, hempcrete, acoustic absorption, GGBS.

I. INTRODUCTION

Hemp-based concretes are bio-aggregate based construction materials that allow for low energy, and sustainable buildings both in construction and in use. Hemp sequesters significant quantities of CO₂ throughout its growth cycle, during which it grows up to 4 meters in 4 months with low fertilizer and irrigation requirement. In the context of building materials, hemp-based concretes exhibit good heat retention [1] and hygrothermal performance [2] primarily due to its high inherent multi-scale porosity.

This paper is focused on the acoustic capabilities of hemp construction. Specifically, it looks at the acoustic absorption of hemp composite walls using binders with hydrated lime and GGBS. These binders are proposed to offer sustainable alternatives to more commonly used cementitious based binders. Extensive investigations of a range of hemp-lime formulations have been previously undertaken that have characterized mechanical as well as moisture transfer and thermal properties [3]. As part of these studies GGBS, was identified as having potential for use in hemp-lime concretes on account of their fast setting and high reactivity [4], [5]. GGBS is a by-product of the iron and steel manufacturing

process. It is created by a polluting industry but is a waste product that would otherwise be disposed of in landfill. Walker and Pavia describe GGBS as a latent hydraulic material which hydrates in the presence of water and as such, it is sometimes not considered a true pozzolan. The self-hydration of GGBS however is very slow but lime acts as an activator [6]. The hydration reaction of GGBS is accompanied by the slower lime-GGBS pozzolanic reaction; the amorphous silica and alumina in the slag react with lime forming additional hydration products.

Designing for acoustic comfort is often an appendix to building projects, achieved in post-occupancy by attaching noise absorbing panels to surfaces. Exposure to high levels of noise constitute risks to health and well-being [7]. Limiting acoustic exposure is particularly pertinent for people of specific age groups; including school children and the elderly. People with dementia are highly sensitive to acoustic discomfort [8]. The contemporary architectural tendency toward open-plan space, an increase in the specification of glass, smooth and polished hard surface finishes, has exacerbated the problem, with noise discomfort commonly reported in post-occupancy evaluations of buildings [9], [10]. Construction methods and building materials that exhibit inherently good sound dissipation properties can offer solutions in environments where excess and reverberated noise is a nuisance, such as classrooms [11], [12].

Highly porous construction materials have the potential to absorb sound and convert it to heat energy within the material pores. Studies have reported the absorption coefficient of fibrous materials [13], aerated autoclaved concrete [14] and concrete using recycled waste concrete aggregate [15].

Some recent studies have focused on the acoustic properties of hemp based concretes [16]. Hemp composites are characterised by high porosity in the range of 70-80% [17]. Pores of different scales exist, including macropores or inter-particle pores between the particles of hemp shiv, mesopores (intra-particle) within shiv and binder and micropores (intra-binder) in the binder. Gle et al. [16], [18] investigated the parameters of fabrication, including density, particle size distribution, type of binder and water content; and how these affect the acoustic properties of hemp concrete with hydraulic and cementitious binders. In the low frequency range, up to 500 Hz, hemp concretes were shown to offer significant sound absorption ($\alpha=0.2$ to 0.5) depending on binder type, with the quick cement binder displaying significantly lower sound absorption capabilities than hydraulic lime binders [16].

This study reports the acoustic absorption characteristics of hemp with a hydrated lime and GGBS binder across a wider

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range of frequencies consistent with salient frequencies of human speech.

II. METHODOLOGY

Acoustic absorption was tested on hemp lime wall sections in a laboratory with minimal background noise. Details of the materials and testing procedure are outlined below.



Fig. 1 Hemp particles of varied scale

A hydrated lime (CL90 – calcium lime) is mixed with GGBS to form the primary binder (termed GGBS in Table I). A second mix (GGBS+WR) includes a water retainer, methyl cellulose, to retain water in the binder and reduce the water adsorbed by the hemp [19].

Wall sections measuring 900x800x300 mm were cast in timber shuttering and allowed to cure for 21 months prior to testing. Replicating common hemp concrete construction methods, the walls were tamped in the shuttering by an experienced practitioner.

TABLE I
MIX PROPERTIES

Label	Composition	Binder:Hemp:Water ratio (by weight)
GGBS	70% CL90, 30% GGBS	2:1:3.1
GGBS +WR	70% CL90, 30% GGBS 0.5% Methyl Cellulose	2:1:3.1

Porosity and density values are listed in Table II. The porosity is measured by water displacement pycnometry [20].

B. Acoustic Testing Procedure

An impedance tube is tightly contacted to the wall surface. A white noise signal is generated using a B&K 1405 noise generator, attenuated with amplifier and transmitted through a speaker down the length of impedance tube.

Acoustic absorption coefficients were calculated in the frequency range 332 Hz up to 2865 Hz with cut-off frequencies defined in the standards [21] and literature [22], for the distance between the microphones (43 mm) and length of tube (963 mm).

A. Materials

The hemp shiv used in this study is grown in Central France and supplied by La Chanvrière De L'aube. Considering the significance of multi-scale porosity, the particle size distribution was evaluated for a sample of hemp used in the walls being tested.

TABLE II
IMPEDANCE TUBE GEOMETRY

Description	Notation	Dimension
Internal diameter of tube	d	70 mm
Length of tube	l	963 mm
Impedance tube wall thickness	t	3 mm
Microphone diameter	$d_{\text{microphone}}$	7 mm
Spacing between microphones	s	43 mm



Fig. 2 Impedance tube contacting section of hemp-GGBS wall

III. RESULTS

A scanning electron microscope (SEM) was used to analyse the hemp concrete samples. SEM images evidence their inherent pore structure [23]. Fig. 3 illustrates the micro-pore structure of hemp concrete with GGBS binder under analysis in this study. Sound absorption was calculated across the range of frequencies to 2000 Hz and its values at key frequencies are listed in Table III.

Table III documents the sound absorption coefficient at the 1/3 octave frequencies 500 Hz, 1000 Hz and 2000 Hz.

The characteristic curves for the range of sound absorption parameters are shown in Fig. 4.

TABLE III
ACOUSTIC ABSORPTION PROPERTIES

Label	Physical Properties		Acoustic Absorption Coefficient		
	Density	Porosity	500Hz	1kHz	2kHz
GGBS	505 kg/m ³	73.3	0.49	0.42	0.44
GGBS +WR	522 kg/m ³	72.5	0.52	0.45	0.53

When the water retainer is added to the mix, a slight (3%) increase in density and decrease in porosity (1%) is observed. The sound absorption coefficient is seen to increase across the frequency range; however, it is likely insensitive to these slight physical changes and instead due to variants in casting or alterations in pore structure.

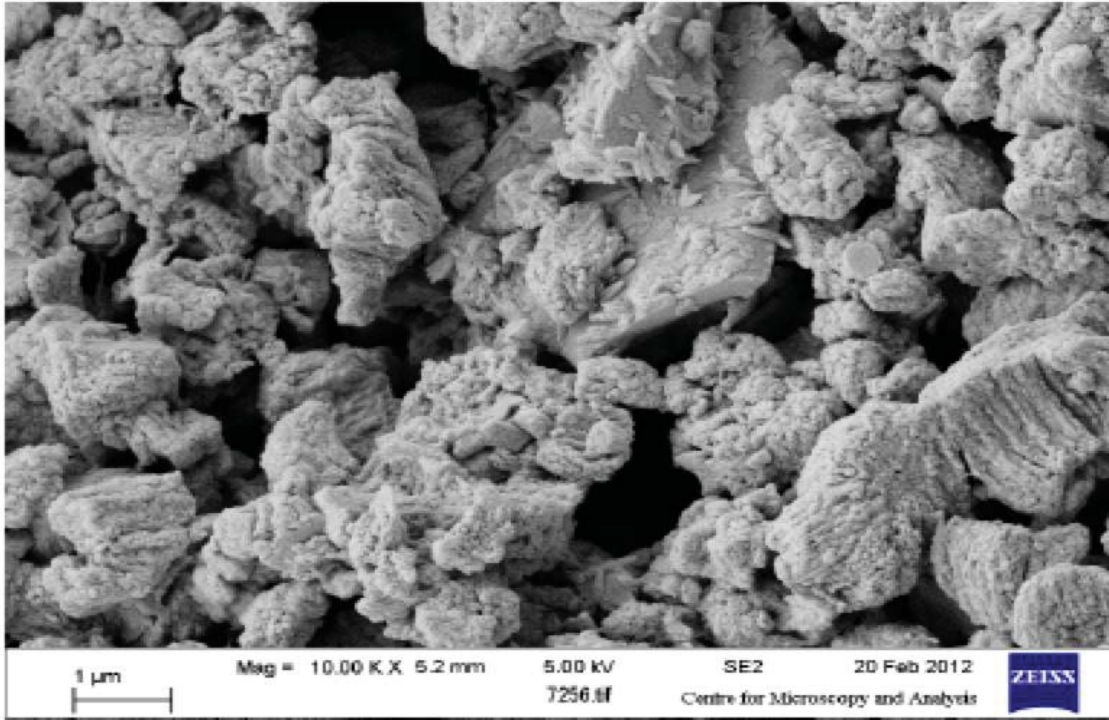


Fig. 3 SEM image of hemp concrete matrix with GGBS binder

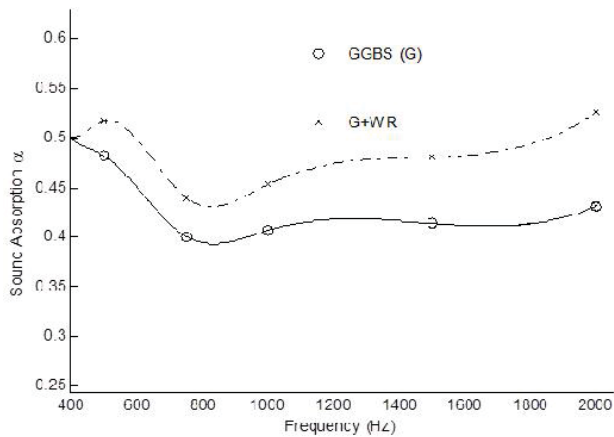


Fig. 4 Characteristic sound absorption curves for hemp concrete

IV. DISCUSSION

Hemp exhibits high sound absorption when combined with lime-GGBS binder. Values reported in this study are similar to those reported by Gle et al. for hydraulic lime binders, and higher than those reported for a binder including cement. However, values documented in this study are consistent over

a wider range of frequencies tested. In a previous study, the acoustic absorption of a range of other wall types were investigated using the impedance tube method in situ [24]. These include wood finishes, fair-faced and painted cinder block and unpainted render walls. Hemp-lime concrete displays good sound absorption when compared to other common building materials although it exhibits sound absorption coefficients slightly lower than porous concrete [15] and fair faced concrete block [24].

V. CONCLUSION

Un-rendered hemp concrete with hydrated lime and GGBS binder exhibits significant acoustic absorption, with average sound absorption of 40-50% of the normal incident signal, across the tested range of frequencies.

Further work will focus on comparing lime based hemp concretes with those containing cement and also look at the impact of lime render on bulk hemp-lime acoustic characteristics.

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