Mechanical, acoustic and thermal performances of Australian hempcretes

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Abstract. This paper is investigating the performance of Australian hemp in hempcrete including unretted and retted hurd and fines for wall and render applications, respectively. The mechanical, thermal and acoustic characteristics of hempcrete are assessed including the effect of retting process. Although the retting process caused about 12% decrease in shiv bulk density, which was attributed to the degradation of hemp and a lower solid volume fraction, hempcrete bulk density, mechanical characteristics, thermal conductivity and acoustic performance are not significantly influenced by the retting process. The thermal conductivity appears to be proportional to the bulk density which is proportional to the hemp content of hempcrete. Acoustic performance of wall mix specimens was outstanding with a maximum sound absorption coefficient around 0.90 for a frequency around 700 Hz. However, the acoustic performance of render mix specimens was extremely poor compared to that of wall mix specimens with a sound absorption coefficient less or equal to 0.13. The combined effects of fine particle size and high binder content is responsible for this drastic drop in sound absorption coefficient. Acoustic performance was much more impacted than thermal conductivity by the hemp fine particle size and high binder content of the render mix.

Keywords: Hemp concrete, Bio-aggregates, Thermal performance, Acoustic performance, Mechanical characteristics

1 Introduction

The use of eco-friendly materials in building and infrastructures has a vital role to decrease the carbon footprint. The built environment contributes around 40% of the total greenhouse gas emissions and as such, is a significant contributor to changes in the climate [1]. Emissions result from construction materials and the process of construction, as well as the operational phase of building lifecycles [2] [3]. The built environment includes buildings and infrastructure such as water and transport infrastructure. Population growth has lead to increased density in urban settlements where central areas, typically with the highest density development, experience higher temperatures known as the urban heat island effect, and poor air quality due to emissions from buildings and vehicles [4] [5]. The changing climate is increasing the incidence and impacts of bushfires, where toxic smoke affects the health of urban populations adversely [6]. Reducing carbon emissions through the specification of low carbon materials, or materials which capture and store carbon, is a way of mitigating the effects of the built environment on the climate [5]. Heat stress and air quality can be ameliorated through adoption of green infrastructure (trees, open green space, green walls and roofs) and use of bio-based building materials [7]. Bio-based materials, derived from plant sources, have become increasingly popular, producing eco-friendly materials with a low carbon footprint. In fact, bio-based materials made from renewable vegetable granulates allow carbon storage during growth [8]. Among these materials, hemp concrete or hempcrete is becoming more and more popular in construction because of its manufacture from renewable resources (plants), and its non-degradable characteristics over time. Hempcrete is generally composed of hemp shiv, woody core parts of the hemp stalk, binder (lime-based cementitious) and water. Depending on the mix design, hempcrete can be used as bricks, as a coating/spraying layer, or as a filling material for wall components. In comparison with conventional building materials, other advantages of hempcrete are its lower density, good acoustic properties, excellent moisture buffer capacity, and good thermal insulation properties [9]. Hempcrete is the most studied bio-based material in Europe. Previous studies have showed that hemp properties influence the mechanical, thermal and acoustic performance of hempcrete. However, the use of hempcrete in building construction remains very limited in Australia and a few numbers of studies [10, 11] have been reported, especially using hemp grown in this country. Recently, a paper by the authors reported an aiming to characterise different types of hemp grown in New South Wales (Australia) including bulk density, water absorption, thermal and acoustic properties. Moreover, the influence of the retting process on these properties was assessed [12]. This paper is investigating the performance of the same Australian shivs in hempcrete. The shivs were mixed with lime and Portland cement in order to target two possible applications: non-load bearing building walls and render applications. The mechanical, thermal and acoustic characteristics of hempcrete are assessed including the effect of retting process. The characteristics of the hemp (particle size distribution, water absorption, initial water content and dry density) influence hempcrete properties. Three different types of hemp grown in New South Wales (Australia) were tested by the authors [12]: unretted small chop hemp hurd, unretted small chop hemp hurd and hemp fines (for more details: see section 3. Raw materials). In spite of different environmental conditions, the properties of Australian shivs were within the same range as European shiv properties. Regarding hemp retting process, the water content of the retted hurd was about 20% higher than that of unretted hurd. After drying, the retting process or the particle size had no significant influence on the water absorption for all immersion times. The retting process caused about 12% decrease in bulk density, which was explained by the degradation of the hemp and a lower solid volume fraction. 12 % decrease in bulk density caused about 5% increase in sound absorption coefficient (without compaction) and 19% decrease in thermal conductivity. Retting process can contribute to improve the insulation performance of hempcrete.

The particle size distribution and the dust ratio were similar for retted and unretted hurds.

2 Raw materials and experimental tests

A low THC hemp variety is used (Frog One), which was cropped in the Dugong region in the Hunter Valley (New South Wales) [13]. Shivs with or without dew retting (for approximately 6 weeks) and manufactured in 2 sizes were sampled from 10 kg bags: sample H-S-UR (Unretted small chop hemp shiv), sample H-S-R (Retted smaller chop hemp shiv), sample H-F (hemp fines). For samples small chop hemp shiv (retted or unretted) and hemp fine, the bulk densities are 160 kg.m^{-3} and 190 kg.m^{-3} and the maximum particle size are 7 mm and 2.5 mm, respectively. Three different commercial mixes, recommended by the supplier, (Table 1) were used to batch hempcrete (a mix lime and Portland binder) samples. A white cement was used for an aesthetic aspect. Wall mix includes samples B-S-R and B-S-UR (200 mm high and 100 mm diameter) in which retted (H-S-R) and unretted (H-S-UR) hemp hurd were used respectively. Render mix includes samples R-F (cube of 50 mm side) in which hemp fines (H-F) were used. The tests were performed after a curing time of 28 days. A two-microphone impedance tube B&K type 4206 was used to conduct the sound absorption measurement based on the transfer-function method following the ISO standard. A Hot Disk system is used to measure the thermal properties based on the transient plane source technique (Figure 1).

Table 1. Mix design (in percentage of mass)

Mix	Hemp (%)	Binder (White Portland cement + Lime) (%)	Water (%)
B-S-R	20	37	43
B-S-UR	20	37	43
R-F	9	44	47

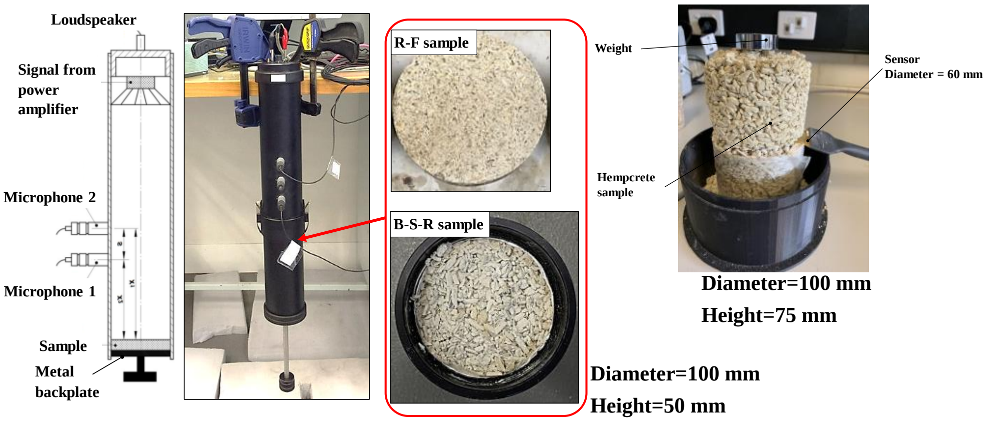

Fig. 1. Experimental setup for the impedance tube system (left side) and the thermal tests with the Hot Disk system (right side) for hempcrete samples.

3 Results and discussion

Figures 2 and 3 compare the bulk density, the compressive strength, the elastic modulus and the thermal conductivity of the three hempcretes tested. The bulk density of the render mix (R-F specimen) with hemp fines is over two times greater than that of the wall mix (B-S-R and B-S-UR specimens). The shiv to binder ratio in mass is 0.56 for wall mix and 0.20 for render (Table 2) which was the reason for the render mix high density. Although, its density is still over three times lower than the typical density of standard concrete. The retting process led to a reduction in the density of small chop hemp hurd. But, the effect of retting process on hempcrete density is only marginal even for a high shiv to binder ratio of 0.56. It is expected that the effect of retting process would have no influence if binder content is increased. The compressive strength of wall mix (specimens B-S-R and B-S-UR specimens) are similar and around 0.15 MPa. Retting process appears to have no effect on hempcrete compressive strength. The compressive strength of render mix (R-F specimen) is much higher, achieving 1.85 MPa due to its higher binder content. Hempcrete compressive strength, within the range of shiv to binder ratio considered (0.20 to 0.56), is overall very low, highlighting that these hempcretes are unlikely to be used without a load bearing frame. The elastic modulus of the three hempcretes tested are low, ranging from 41 to 54 MPa for wall mix (B-S-R and B-S-UR specimens) and around 520 MPa for render mix (R-F specimen) which would allow hempcrete to accommodate large mechanical and thermic deformations without cracking. For the same reason as for compressive strength, the higher binder content of render mix led to an elastic modulus over ten times greater than that of wall mix. The influence of retting process on thermal conductivity is only marginal. According to a previous study, the thermal conductivity of hempcrete can range from 0.11 $W.m^{-1}.K^{-1}$ for dry samples to 0.32 $W.m^{-1}.K^{-1}$ for samples at 100 % RH. In this study, providing that specimens were stored in 60 % RH and were compacted, the thermal conductivity coefficients measured, between 0.137 and 0.284 $W.m^{-1}.K^{-1}$, are within the same range.To compare the mechanical characteristics measured to test results from the literature, a multicriteria analysis (Figure 4) was performed on wall mixes (B-S-R and B-S-UR specimens) for which more data are available. An unidimensional scale ranging between 0 to 10 was used, the highest value of each characteristic obtaining 10 marks. The variation between the maximum and minimum values reported in the literature depend mainly on the hemp content. As expected, in the light of the previous results on hemp particles [12], the properties of hempcrete with Australian shiv are within the same range as that of European hempcrete.

Figure 5 compares, for wall mixes (B-S-R and B-S-UR specimens) and render mix (R-F specimen), the ratios between hemp content in mass, bulk density and thermal conductivity. Figure 5 also shows the sound absorption coefficient of hempcrete measured within the frequency range 300 to 1800 Hz. Thermal conductivity is proportional to bulk density, which is proportional to hemp content in the mix. These results are consistent with previous studies, which concluded that thermal conductivity decreases linearly with the decrease in bulk density (depending on hemp content). However, results showed that, for high contents of shiv in mass (above 30 %), thermal conductivity is no longer linearly proportional to bulk density suggesting that it is not valuable to increase further the amount of hemp in the mix. The results are consistent with a previous study investigating similar wall and render mixes, using equivalent experimental procedures, specimen sizes and hemp contents. The maximum sound absorption coefficient of wall mix (B-S-R and B-S-UR specimens) for a frequency around 700 Hz is 0.90 and 0.92 respectively. Acoustic performance of hempcrete with coarse hemp particles with high hemp content is outstanding, showing no significant influence of retting process. However, the performance of the render mix (R-F specimen) is poor with a sound absorption coefficient less or equal to 0.13. Although, the sound absorption coefficient of particles of hemp shiv (H-S-R and H-S-UR samples) and hemp fine (H-F sample) were similar, the poor acoustic performance of R-F specimen seems to be due to the combined effects of using hemp fines composed of dust and fibres and high binder content. For the render mix, inter-particles voids are filled with binder paste resulting in a drastic reduction in air filled voids which are efficient in trapping sound. Most of the pores within the cement paste are way too small to efficiently dissipate acoustic waves. This reduction in hempcrete porosity and air-filled voids is leading to this drastic decrease in sound absorption coefficient. Moreover, after sawing the samples, the surface exposed to the acoustic waves of the render mix (R-F specimen) is much smoother than the surface of wall mixes specimens (B-S-R and B-S-UR specimens), which can as well contribute to a further decrease in sound absorption coefficient. It is worth noticing that hempcrete sound absorption coefficient was much more impacted than thermal conductivity, which depends more on the total porosity than the pore size distribution and interconnectivity.

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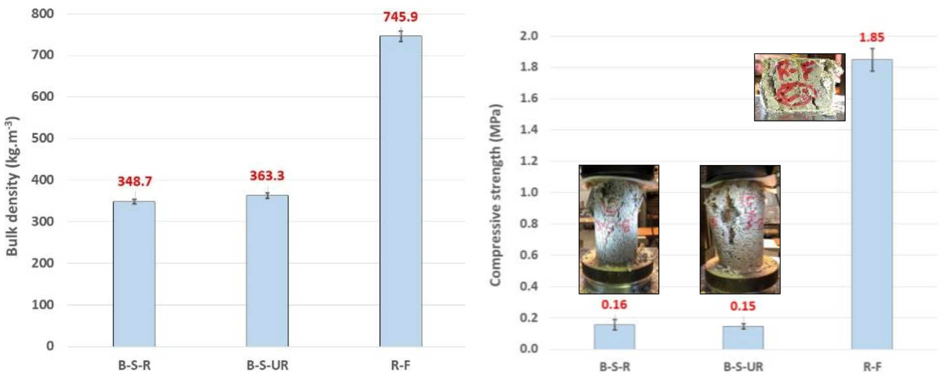

Fig. 2. Bulk density and compressive strength of hempcrete samples at 28 days.

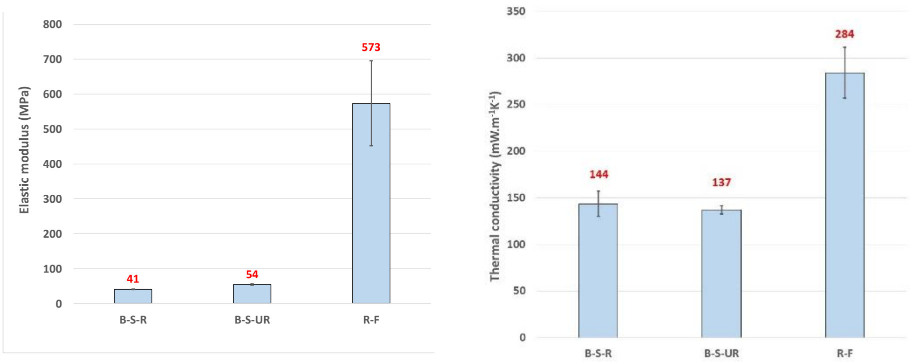

Fig. 3. Elastic modulus and thermal conductivity of hempcrete samples at 28 days.

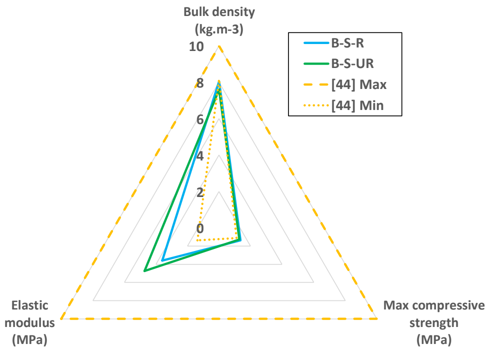

Fig. 4. Comparison between characteristics of the tested hempcretes and characteristics of European hempcretes.

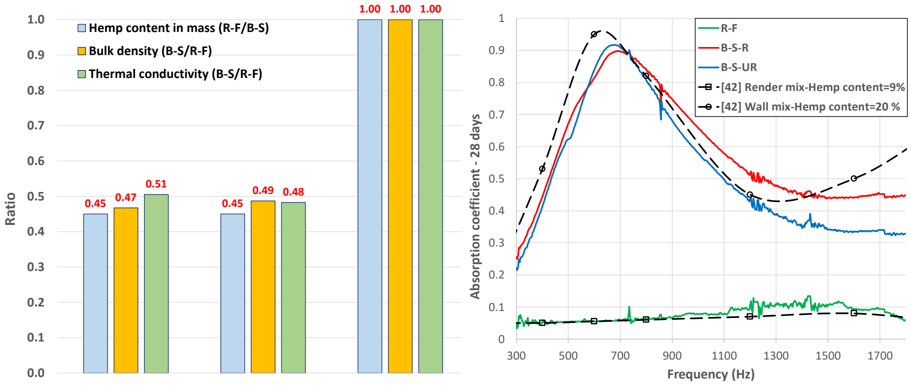

Fig. 5. Comparison between the wall mix (B-S-R and B-S-UR samples) and the render mix (R-F samples) (left side) and sound absorption coefficient at 28 days (right side)

4 Conclusions

As reported previously in the literature, hempcrete bulk density is mainly governed by its hemp content. For the specimens tested, the bulk density was ranging from 350 to 745 kg.m-3 for shiv to binder ratios of 0.56 and 0.20, respectively. Hempcrete compressive strength, within the range of shiv to binder ratio considered, is overall very low, highlighting that hempcrete is unlikely to be used without a load bearing frame. The elastic modulus of the three hempcretes tested were low, ranging from 41 to 54 MPa for wall mixes and around 520 MPa for the render mix which would allow hempcrete to accommodate large mechanical and thermic deformations without cracking. Increasing the binder content allows increasing both compressive strength and elastic modulus of hempcrete. Overall, the mechanical properties of hempcrete with Australian shiv are within the same range as mechanical properties reported for European hempcretes. The thermal conductivity coefficients measured were ranging from 0.137 to 0.284 $W.m^{-1}.K^{-1}$ and are in the same range of results reported in the literature. The thermal conductivity appears to be proportional to the bulk density which is proportional to the hemp content in the mix. Acoustic performance of wall mixes was outstanding with a maximum sound absorption coefficient around 0.9 for a frequency around 700 Hz. However, the acoustic performance of the render mix was extremely poor compared to the wall mixes. Results suggest that the combined effects of fine particle size and high binder content is responsible for this drastic drop in sound absorption. Acoustic performance was much more impacted than thermal conductivity. The retting process appears to have no significant influence on hempcrete bulk density, mechanical characteristic, thermal conductivity, and acoustic performance even for a high shiv content. Research on the development of an ecofriendly binder, to mix with Australian hemp, are ongoing in order to provide a sustainable material with high insulation properties.

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