

Overview on bio-based building material made with plant aggregate

Amziane, S., & Sonebi, M. (2016). Overview on bio-based building material made with plant aggregate. *Rilem Technical Letters*, *1*, 31-38. http://letters.rilem.net/index.php/rilem/article/view/9/11

Published in:
Rilem Technical Letters

Document Version:
Publisher's PDF, also known as Version of record

Queen's University Belfast - Research Portal:
Link to publication record in Queen's University Belfast Research Portal

Publisher rights
© 2016 S. Amziane, M. Sonebi
This is an open access article published under a Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution and reproduction in any medium, provided the author and source are cited.

General rights
Copyright for the publications made accessible via the Queen's University Belfast Research Portal is retained by the author(s) and / or other copyright owners and it is a condition of accessing these publications that users recognise and abide by the legal requirements associated with these rights.

Take down policy
The Research Portal is Queen's institutional repository that provides access to Queen's research output. Every effort has been made to ensure that content in the Research Portal does not infringe any person's rights, or applicable UK laws. If you discover content in the Research Portal that you believe breaches copyright or violates any law, please contact openaccess@qub.ac.uk.

Download date:21. Mar. 2022

RILEM Technical Letters (2016) 1: 31 – 38

Overview on bio-based building material made with plant aggregate

Sofiane Amziane[a], Mohammed Sonebi[b]

[a] Institut Pascal, UMR 6602, Clermont University, Clermont Ferrand, France
[b] School of Planning. Architecture and Civil Engineering, Queen's University Belfast, Belfast BT7 1NN, UK

Received: 04 May 2016 / Accepted: 10 May 2016 / Published online: 02 June 2016
© The Author(s) 2016. This article is published with open access.

Abstract

Global warming, energy savings, and life cycle analysis issues are factors that have contributed to the rapid expansion of plant-based materials for buildings, which can be qualified as environmental-friendly, sustainable and efficient multifunctional materials. This review presents an overview on the several possibilities developed worldwide about the use of plant aggregate to design bio-based building materials. The use of crushed vegetal aggregates such as hemp (shiv), flax, coconut shells and other plants associated to mineral binder represents the most popular solution adopted in the beginning of this revolution in building materials. Vegetal aggregates are generally highly porous with a low apparent density and a complex architecture marked by a multi-scale porosity. These geometrical characteristics result in a high capacity to absorb sounds and have hygro-thermal transfer ability. This is one of the essential characteristics which differ of vegetal concrete compared to the tradition mineral-based concretes. In addition, the high flexibility of the aggregates leads to a non-fragile elasto-plastic behavior and a high deformability under stress, lack of fracturing and marked ductility with absorbance of the strains ever after having reached the maximum mechanical strength. Due to the sensitivity to moisture, the assessment of the durability of vegetal concrete constitutes one of the next scientific challenging of bio-based building materials.

Keywords: Bio-based building materials; Vegetal aggregates; Sustainability; Physical properties; Life cycle analysis

1 Introduction

The concept of sustainable development dealt with locally is often linked to problems on a worldwide scale, such as global warming or the gradual exhaustion of resources. These two criteria constitute the points of no return for our civilization [1, 2]. The preservation of the environment is one of the principal features of sustainable development with the urge to reduce green house gas (GHG) emissions [2-6]. Total GHG emissions by economic sector in 2010 which includes the direct emissions were: 25% for electricity and building heat production, 6.4 % for construction buildings, 14 % for transport, 21 % for industry, 9.6% for other energy and 24% for Agriculture, Forestry and Other Land Use (AFOLU); and the indirect emissions were: 1.4 % for energy, 11 % for industry, 0.3 % for transport, 12 % for building and 0.87 % for AFOLU [7]. For its part, the construction sector finds itself facing significant challenges in terms of reducing GHG emissions and energy consumption [4, 5] by using alternative materials.

The estimation made in 2009 by the International Energy Agency (between 3.36 and 3.48 billion tonnes in 2015) for long-term evolution of the cement demands (used in construction) is already overcome with an estimated annual worldwide cement production in 2014 of 4.3 billion tonnes, i.e. an increase of 6.7 % from 2013. In summary, the construction sector battles four main impacts on the environment: its GHG emissions; its energy consumption; its consumption of natural resources; its waste production. As alternative, plant based materials have a valuable benefit for health, ecologic, comfortable habitat (moisture management, thermic and acoustic) and sustainable materials [8, 9]. Global warming, energy savings, and life cycle issues are factors that have contributed to the rapid expansion of plant-based materials for buildings, which can be qualified as environmental-friendly and efficient multifunctional materials. Concerning energy savings, most of thermal code in Europe requires that from 2020 on, all new buildings meet the positive energy criteria. This improvement of energy performance of buildings induces modifications in the distribution of environmental impacts (Figure 1), and places the manufacture of the building materials as the most important phase when the energy consumption decreases from 200 to 15 kWh/m²/yr [10, 11]. So, to reduce these impacts, it makes sense to go on moving towards plant-based materials, whose impacts are very limited, and can even be positive on the environment.

2 Development of agro-concretes

The introduction of a high concentration of bio-aggregate-building material in the construction design is the fundamental principle of this concept. The use of crushed hemp (shiv), flax and other plants associated to mineral binder represents the most popular solution adopted in the beginning of this revolution in building materials [8, 10].

*Corresponding author: Sofiane Amziane, sofiane.amziane@univ-bpclermont.fr

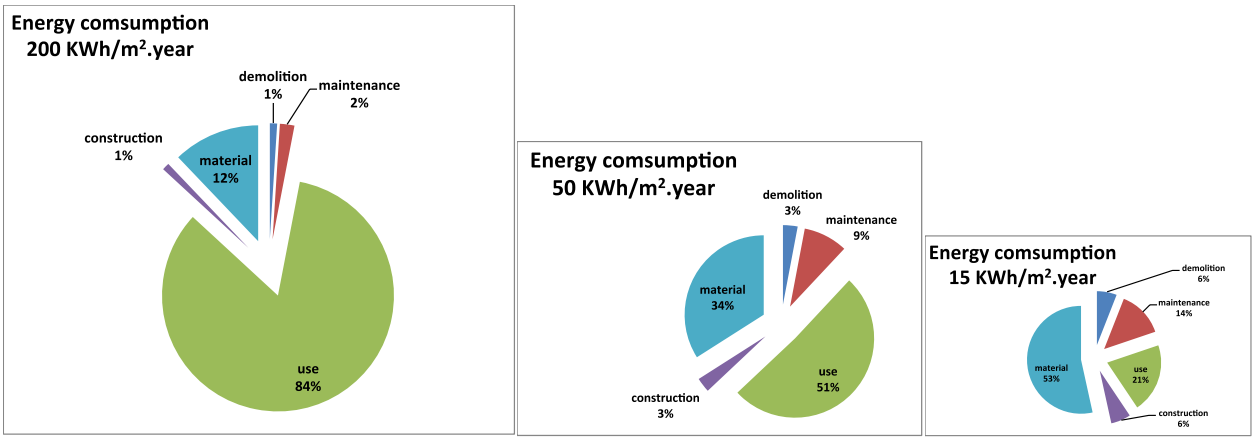


Figure 1. Distribution of environmental impacts between the different phases of a construction depending on its energy performances.

Around the main markets generated by a cereal or petroleum culture, there are a great many secondary markets springing up, which will facilitate as complete a value creation as possible. Such is the case, in particular, for hemp, for which the corners of the market are as varied as fibers for the automobile industry, foodstuffs for the grain or indeed the wood of the stem for construction [12]. The quantities and the sources available are abundant. Hence, vegetable biomass has a bright future.

3 What does the term "Agro-concrete" mean?

A concrete in the conventional sense of the word consists of a heterogeneous mix between a mineral binder and granulates (also mineral in origin) of graduated dimensions [3]. Similarly, that which we define as Agro-concrete will therefore consist of: "A mix between granulates from lignocellular plant matter coming directly or indirectly from agriculture or forestry, which form the bulk of the volume, and a mineral binder" [8].

Indeed, many projects aim to create construction materials using one or more forms of lignocellular matter as a reinforcement to the structure rather than as a lightweight aggregate with an insulating purpose. The materials used are generally fibers which serve to improve the traction resistance, ductility and post-fracture behaviour of composite concretes made in this way. More recently, projects used various sources of bio-aggregates, such as wood, coconut, sisal, palm, bamboo, or bagasse, etc. (Table 1). It is interesting to note that countries such as Brazil which have an exceptional range of flora have a wide range of fibers to experiment with, and research in this domain is very active [13, 14].

4 Properties of plant aggregate

Bio-based aggregate are coming from the stem of plants cultivated either for their fibers (hemp, flax, etc.) or for their seeds (oleaginous flax, sunflower, etc.) (Table 1). Owing to the structure of the stem of the plant they are made from, such aggregates are generally malleable, elongated and highly porous with a low apparent density. They are very different from the mineral aggregates typically used in concretes, for which there are standardised tools and techniques for characterisation. Amongst these, hemp shiv (the woody core of the stem of the hemp plant) is probably the most widely used in alternative or eco-friendly building materials in Europe and is also representative of most of the aggregate coming from the stem of an annual crop. This is usually mixed with a lime-based binder and the resultant bio-concrete is known as *hemp-lime*.

This kind of aggregate is a co-product of hemp industry that is renewable and produced in an annual cycle while the price of mineral aggregates is steadily increasing as resources become less readily available. The characterization of these aggregates, however, which is crucial to a proper understanding of the quality of the materials in which they are incorporated, requires adaptations to be made to the techniques usually employed for mineral aggregates, or the devising of new characterization procedures [63].

The hygroscopic behaviour of lignocellulosic plants is largely due to their hydrophobicity. Their complex architecture is marked by a multi-scale porosity in order to conduct the necessary fluids for their development (sap and water). Even after cutting and processing, this porosity continues to play its role and is therefore the main way of absorption of water following the Laplace laws. This absorption occurs mainly by conducting vessels or tracheids before the water spreads to the rest of the cells by diffusion through the cell walls and punctuation. The typical value of absorption is about 350 % [64, 66].

The bulk density of hemp shiv is linked to the porosity of the particles and to the inter-particular porosity. The bulk density of hemp shiv is measured in a cylindrical mould with a loose packing and without compaction. The typical value obtained is about 100 kg/m^3 [8, 13, 65]. The particle size distribution of bio-aggregate may be studied via sieving method and/or image analysis [8, 15].

Table 1. Overview of research into materials mixing mineral binders and lignocellular products for making of lightweight concretes.

Plant	Valuable material	Source(s)	Binder(s) used	Countries	References
Hemp	Hemp wood	Agricultural co-product	Tradical® PF70, hydraulic lime, methacholine/lime mix	France Elsewhere	[10, 15-22] [23-27]
Flax	Shive, tow	Agricultural co-product	Portland cement, Cement + Sucrose	France	[28-30]
Wood (all types)	Sawdust, shavings	Sawmill waste	Portland cement, Cement/clay mix Portland cement	France Elsewhere	[31-33] [34, 35]
Sunflower	Stem	Agricultural by-product	Methacholine/lime mix	France	[10, 36]
Beetroot	Dried beetroot pulp	Food industry waste	Portland cement	France	[37]
Coconut	Shell	Food industry waste	Portland cement	Elsewhere	[38]
Durian	Shell	Food industry waste	Portland cement	Elsewhere	[38, 39]
Cork	Wood	Industrial waste	Portland cement	Elsewhere	[40]
Miscanthus	Stem	Co-product (ethanol)	Portland cement	France	[41]
Rice husk	Husk	Agricultural by-product	Lime	France	[42]
Corn Cob	Cob	Agricultural by-product	Cement	Portugal	[43]
Lavender	Straw	Agricultural by-product	Calcic lime	France	[44]
Dis	Stem	Wild plant	Cement	Algeria	[45]
Alfa	Fibres	Wild plant	BioPolymer	Algeria	[47]
Tipha, Catail	Stem	Wild plant	Methylene Diphenyl Diiso-cyanate binder	Senegal Germany	[48, 49]
Date palm	Fibres	Agricultural by-product	Cement	Algeria	[50]
Beet pulp	Pulp	Food industry waste	Cement/Lime	Nederland	[37, 46]
Durian, Rambutan, Pumello, Mangusteen	Peel	Agricultural by-product	Cement/Sand	Thailand	[38, 39]
Coir	Fibres	Agricultural by-product	Cement	India	[52]
Rape straw	Fibres	Agricultural by-product	Lime/Cement	France	[53]
Opuntia ficus-indica	Cladodes	Agricultural by-product	Resin	Italy	[54]
Sugar cane bagasse		Food industry waste	Cement / Soil	USA	[55]
Bamboo		Wild plant	Cement	China	[63]
Lechuguilla fibres		Wild plant	Cement	Mexico	[57]
Kenaf bast fibres		Wild plant	Cement	USA/Brazil, Malaysia	[58]
Wood shaves		Wild plant	Cement	Algeria/ France/Brazil	[59, 60]
Sulphite pulp fibres		Wild plant	Cement	Brazil	[61]
Eucalyptus kraft pulp		Wild plant	Cement	Australia	[62]

5 Binders

Various binders may be used to make construction materials based on granulates and fibers of plant origin. The choice is essentially made on the basis of the main properties sought (mechanical properties, thermal properties, etc.), which will depend on the material use (support, insulation, etc.), the manufacturing process (prefabricated in a factory, poured on site, projected ("shotcrete"), etc.) and on the construction location (indoors, outdoors, sheltered or otherwise) [68]. The choice may also be guided by financial considerations (e.g. local prices of materials) and environmental factors (CO_2 balance, for instance) [68].

Among the most commonly used materials, we find Portland cements and hydraulic or aerated lime, most often associated with pozzolanic additives such as fly ash, blast furnace slag and metakaolin [8, 65, 69]. We also find plaster for applications where it is sheltered from humidity. Certain commercial binders developed specifically for hemp concrete (hempcrete) are also obtained by mixing these different compounds: for instance, 70% slaked lime, 15% hydraulic lime and 15% pozzolana [8, 68].

6 Multiphysical Properties of Hempcrete

Hempcrete is a mixture, in very changeable proportions, of two very different components: a plant-based granulate and a hydraulic and aerated setting binder. It exhibits multi-physical behaviour which is unusual in the domain of construction materials. Indeed, the particles of hemp wood are characterized by a high degree of porosity which results in a high capacity to deform, absorb sounds and have hygrothermal transfer ability: this is one of the essential characteristics which set hempcretes apart from tradition mineral-based concretes for which the granulates are considered non-deformable. This difference has major effects on the performances of these concretes in all areas (acoustic, thermal [66], etc.), and of course, it has a direct impact on the mechanical properties of these innovative concretes [66, 67]. The aim of this part is to show why and how these concretes are distinguished from conventional concretes, and in particular to establish the properties of use and the characteristic values necessary for their use in construction.

6.1 Mechanical properties

As a mixture of plant particles and binder, hempcrete is an unusual construction material: the high flexibility of the aggregates in conjunction with the rigidity of the cement matrix leads to a non-fragile elasto-plastic behaviour. Thus, it is distinguished from other construction materials by a high deformability under stress, lack of fracturing and marked ductility with absorbance of the strains ever after having reached the maximum mechanical strength [66].

It is also helpful to highlight another peculiarity: the variability of the behaviour depending on the formulation enables us to adjust and optimize the performances of this material for diverse applications as a roof filling material, in walling or as flagging (Figure 2). Depending on the concentration of binder, three types of behaviours of hempcrete are observed. For small doses of binder, we have a material with poor mechanical strength and an elastic modulus of less than 5 MPa. The levels of deformation are very high (>15%) [8]. This material behaves like a sample of loose particles with bridges of binder connecting them. It is pre-destined for applications where thermal or acoustic insulation is important. For intermediary doses, the level of performance increases with the quantity of binder. The behaviour of the material becomes progressively more similar to that of materials with large doses of binder. The behaviour is guided by the binder matrix. For large doses of binder, the material is comparable to a continuous binder matrix in which the plant particles are buried. The mechanical performances increase and tend towards those of the pure binder. However, the high deformations that this concrete is capable of dealing with make it advantageous as a filling material. It can undergo differential compression, contraction or dilation with no apparent cracking [26].

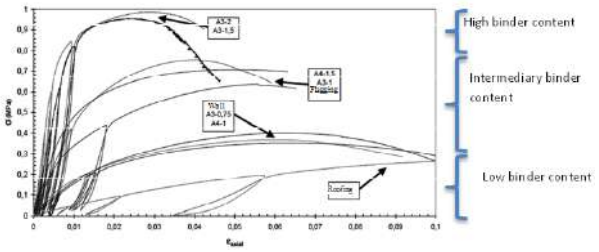


Figure 2. Influence of the dose of binder on the compressive strength of the hempcrete shaped by compaction (0.05 MPa) after 1 y of hardening, reproduced from [16].

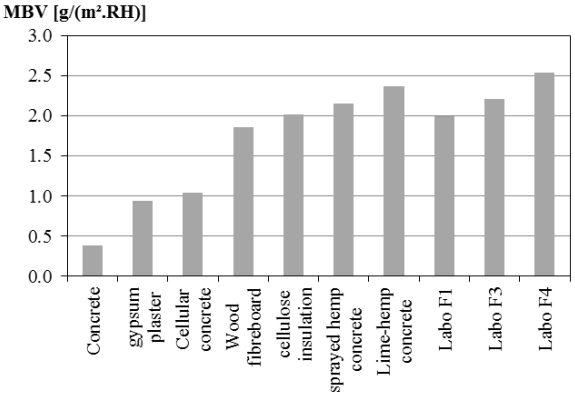


Figure 3. Review of Moisture buffer value of building materials, reproduced from [73].

6.2 Hygrothermal properties

The building of dwellings or renovation work including hemp-based materials often draw initial comments from users that are very positive in regard to the thermal and hygrothermal conditions. The particular reason behind this fact is their high porosity (between 70% and 80%) resulting in excellent insulating properties [72], see Fig. 4.

Hemp-based materials are considered as phase-change materials (PCM): the thermal behaviour reduces the amplitude of the variations in the ambient air temperature, whilst improving the thermal comfort by bringing down the surface heat of the material. Thus, the use of such materials is an excellent means of passively regulating the indoor temperature, and thereby decreasing the building's energy requirements [72]. In addition, the experimental results show a regulation of the relative humidity in the envelope because of constant exchanges of water vapour between the indoor and outdoor environments, modulating sudden changes in temperature. Hence, these materials are able to improve summer and winter comfort, and stabilize the indoor temperature between day and night, whilst preventing the phenomena of condensation and dampness on the walls [73]. Some examples of MBV value are given in Fig. 3 for concrete and cellular concrete from [74], gypsum plaster, wood fibreboard and cellulose insulation from [75], sprayed hempcrete (hemp concrete) from [73], lime-hemp concrete from [76], hemp lime concretes with increasing substitution of lime-based binder for sulphate-based binder (F1: 1/3 sulphate-based binder + 2/3 lime-based binder; F2: 1/2 + 1/2; F3: 2/3 + 1/3) [77]. These properties are also well summarised in reference [78].

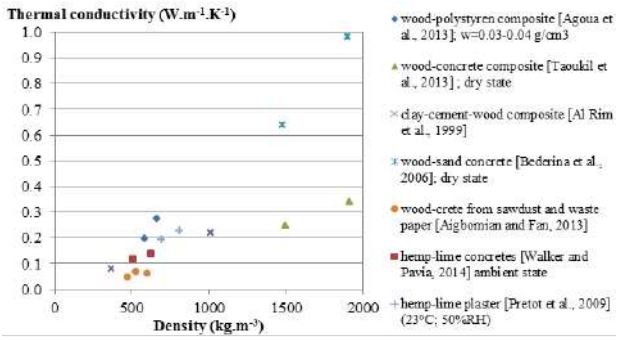


Figure 4. Thermal conductivity of bio aggregate based building composites (made of wood or hemp shiv).

6.3 Acoustic properties

Hempcrete is a material whose acoustic properties can vary greatly depending on the properties of its components and the way in which it is put to use [79, 80]. In particular, the results presented herein highlight that the parameters of installation have a far stronger influence than the properties of the components, with the apparent density of the material and the binder-to-shiv mass ratio playing an important part (Fig. 5). Thus, by combining these different parameters, it is possible to find the optimal formulation of a hempcrete for any given application.

6.4 Life Cycle Analysis of Hempcrete

Approximately 1.8 tons of CO_2 are sequestered for every ton of hemp shiv used [93]. One cubic meter of hempcrete uses 1000 litres of hemp hurds meaning that around180 kg of CO_2 dioxide will be locked up per 1 m^3 of wall in the hemp shiv [94]. Taking into account the CO_2 emitted for binder production and depending on the re-carbonation of the lime, 117 kg to 18 kg of CO_2 are sequestered into a one cubic meter of hempcrete [95]. This is equivalent to 6 to 38 l of fossil fuel using a CO_2 factor equal to 3.09 kg/l of fossil fuel.

In addition, according to the study published by [81] there is a favorable impact on the greenhouse effect; the hempcrete wall constitutes an interesting carbon absorber for a duration of at least 100 years, because it stores more CO_2 in its three carbon absorbers (i.e. the hemp shiv, wood and lime) than is emitted by its life-cycle (net balance of 35 kg CO_2 eq. stored over 100 years per m^2 of hempcrete wall) (Fig. 6). In time, the CO_2 stored in the organic parts of the wall will be restored to the atmosphere [8, 81].

6.5 Durability of bio-based materials

Because of their relatively recent development, few studies have focused on the durability of plant concrete until now [82, 92]. The aging protocols applied in laboratory and the analysed properties are diverse, making the comparison of obtained results very complex [83]. In addition, the aging times used are rather short, and significant variations of the material properties are perhaps not visible for these aging durations. The protocols implemented until now are focused on similar factors that could influence the material properties: temperature, relative humidity, immersion in water [85, 86] and potential microbiological growth [84]. This can lead to a physicochemical and microstructural modifications of the materials and therefore impact the performances of materials in a building.

An interfacial area of few dozen micrometers thick around plant aggregates can be observed in concrete [88]. In this area, the setting of the binder is inhibited or delayed by the extractable of shiv solubilised during the fabrication, or corresponding degraded products of shiv in an alkali environment. This interfacial transition zone is characterised by an increase of the porosity between the aggregate and the binder. These debonding areas can also be related to the vegetal dimensional changes depending on the material moisture content [87].

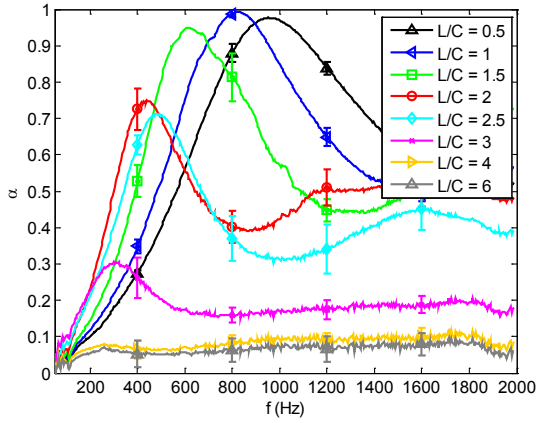


Figure 5. Sound absorption of hempcretes depending on the binder content [79. 80].

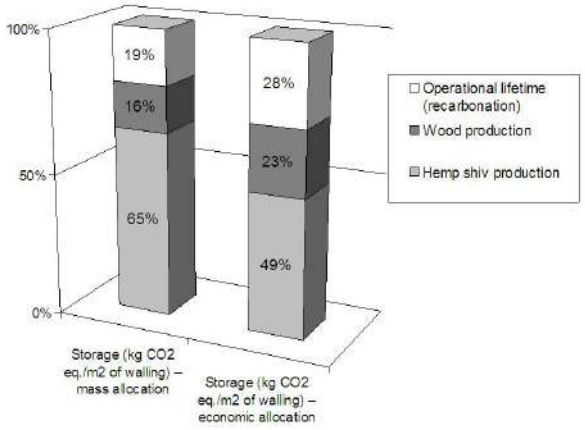


Figure 6. Distribution of the storage of CO2 between the three carbon absorbers in the banked hempcrete wall on a wooden skeleton, reproduced from [8].

Phenomena of degradation of the plant fibres can also be observed when a binder with highly alkaline pH is used [88, 89]. Then, degradation is due to lime crystallisation in the aggregate porosity or a partial or total dissolution of cellulose, hemicelluloses, and for certain kinds of plants, lignin, which leads to the embrittlement of concretes [90].

Some studies have shown that wetting/drying cycles, used to simulate natural variations of humidity, had an influence on the mechanical and thermal properties of hempcretes [84-86].

Finally, in some circumstances, as in the case of fibre-cement panels, fungi may also appear at the surface of materials. This fungal development can lead to changes in functional properties of materials, but also cause health problems by degrading the indoor air quality. Indeed, many studies [88, 89] have investigated the colonisation of different media by molds or fungi (walls, painting, wallpapering, wood, etc.). This development is possible whenever microorganisms have enough water. Fungal species most commonly isolated belong to the Penicillium, Aspergillus and Cladosporium types [91]. Colonisation of fungi and degrees of alteration depend on various factors such as support (nature, physico-chemical properties, surface, water content, pH), microorganisms and environmental conditions [91].

7 Conclusions

Bio-based building materials made with plant aggregates have a lot of potential in the market for construction materials worldwide. With modern building designs demanding ever increasing sustainability in construction and maitenance, efficiency in operating and carbon footprint reduction, bio-based building materials are able to help meet these demands. The material can be naturally grown in plentiful supply across countries with temperate climates, it offers improved insulation and absorbs carbon dioxide from the environment.

The unique selling point of bio-based building materials made with plant aggregate is its ability to effectively insulate a building, using a natural material. However, bio-based building materials typically exhibit a comparatively low mechanical strengths, which is reported in the paper. Due to this low mechanical strength, bio-based building materials cannot be commonly used as a material to form load bearing members of a building, however t well suited to form the fabric of a timber framed dwelling, or other modest timber frame constructions. Bio-based building materials can also be retro-fitted to a building by method of a prefabricated cladding sheet, which can be fixed to the exterior or interior of building, commonly large warehouses, to aid with insulation and carbon offsetting.

Bio-based building materials have proven to have both viability and marketability in the construction industry, despite their relative infancy as a material. As is to be expected with such a new material, limited research has been carried out as to how to best utilize it, particularly with regard to how to take advantage of its natural, low carbon, features as well as its mechanical capacity, i.e. its ability to carry load. These natural features reduce the carbon footprint of a building and improve the insulation, both thermal and acoustic. These features are the main focus of the argument to further research this material, and how it can best be used in the construction industry.

References

[1] United Nations Environmental Program, New science and developments in our changing environment. UNEP, 2009.
[2] United Nations, Kyoto Protocol. United Nations, 1998.
[3] J. Kline, L. Barcelo, Cement and CO_2, a victim of success! In: Cement Industry Technical Conference, IEEE-IAS/PCA 53rd, 2012, 1-14.
[4] CEMBUREAU. World Cement Production 2014. Available at www.cembureau.be. Accessed April 2016.
[5] US Department of Energy, Buildings Energy Data Book 2010, D&R International, 2011.
[6] Department Energy and Climate Change (DECC). Statistical Release: 2011 UK Greenhouse Gas Emissions, Final Figures, 2012.
[7] International Panel on Climate Change (IPCC), Climate Change Indicators: Global Greenhouse Gas Emissions. 2014, www.epa.gov/climatechange/indicator.
[8] S. Amziane, L. Arnaud (Ed.), Bio-aggregate-based Building Materials: Applications to Hemp Concretes. ISTE Ltd and John Wiley & Sons, 2013.
[9] V. Nozahic, S. Amziane, G. Torrent, K. Saïdi, H. De Baynast, Design of green concrete made of plant-derived aggregates and a pumice-lime binder. Cem Concr Comp (2012) 34: 231-241.
[10] C. Magniont, Contribution à la formulation et à la caractérisation d'un écomatériau de construction à base d'agroressources. PhD Thesis, Toulouse, 2010.
[11] B. Peuportier, Eco-conception des bâtiments et des quartiers. Presses de l'Ecole des Mines, Paris, 2008.
[12] P. Bouloc, S. Allegret, L. Arnaud and Collective, Le chanvre industriel: Production et utilisations. Editions France Agricole, 2006.
[13] H. Savastano, V. Agopyan, Transition zone studies of vegetable fibre-cement paste composites. Cem Concr Comp (1999) 21: 49-57.
[14] V. Agopyan, J. Savastano, V. John, M. Cincotto, Developments on vegetable fibre-cement based materials in Sao Paulo, Brazil: an overview. Cem Concr Comp (2005) 27 (5): 527-536.
[15] L. Arnaud, Mechanical and thermal properties of hemp mortars and wools: Experimental and theoretical approaches. Proceedings of 3rd International Symposium on Bioresource, hemp and other fiber crops, Wolfsburg (Germany), 2000.
[16] V. Cerezo, Propriétés mécaniques, thermiques et acoustiques d'un matériau à base de particules végétales. Doctoral Thesis, INSA de Lyon, 2005.
[17] F. Collet, , J. Chamoin , S. Pretot , C. Lanos, Comparison of the hygric behaviour of three hemp concretes. Ener Build (2013) 62: 294–303.
[18] S. Elfordy, F. Lucas, F. Tancret, Y. Scudeller, L. Goudet, Mechanical and thermal properties of lime and hemp concrete ("hempcrete") manufactured by a projection process. Constr Build Mater (2008) 22: 2116-2123.
[19] F. Collet, M. Bart, L. Serres, J. Miriel, Porous structure and water vapour sorption of hemp-based materials. Constr Build Mater (2008) 22: 1271-1280.
[20] D. Samri, Analyse physique et caractérisation hygrothermique des matériaux de construction: approche expérimentale et modélisation numérique. PhD Thesis, Lyon, 2008.
[21] TT. Nguyen, V. Picandet, P. Carre, T. Lecompte, S. Amziane, C. Baley, Effect of compaction on mechanical and thermal properties of hemp concrete. Europ Env Civ (2010) 14 (1-10): 545-560.
[22] T.T. Nguyen, V. Picandet, S. Amziane, C. Baley, Influence of compactness and hemp hurd characteristics on the mechanical properties of lime and hemp concrete, Europ Env Civ (2009) 13: 1039-1050.
[23] A. Evrard, Transient hygrothermal behaviour of lime-hemp materials. Doctoral Thesis, Université Catholique de Louvain (Belgium), 2008.
[24] P.Y. Butschi Utilisation du chanvre pour la préfabrication d'éléments de construction. Doctoral Thesis, Université de Moncton (Canada), 2004.
[25] R. Eires, JP. Nunes, R. Fangueiro, S. Jalali, A. Camões, New eco-friendly hybrid composite materials for civil construction. Proceedings of the 12th European conference on Composite Materials, Biarritz, 29 August-1 September 2006.
[26] PB. de Bruijn, K. Jeppsson, K. Sandin, C. Nilsson, Mechanical properties of lime-hemp concrete containing shives and fibres. Bios Eng (2009) 103: 474-479.
[27] E. Hirst, P. Walker, K. Paine, T. Yates, Characterisation of Low Density Hemp-Lime Composite Building Materials under Compression Loading. 2010, Actes de la 2ème conférence Internationale sur les Matriaux et Technologies de la construction durable, Ancona (Italy), 28-30 Juin 2010.

[28] M. Khazma, N. El Hajj, A. Goullieux, RM. Dheilly, M. Queneudec, Influence of sucrose addition on the performance of a lignocellulosic composite with a cementious matrix. Comp Part A: App Sci Man (2008) 39: 1901-1908.
[29] E. Aamr-Daya, T. Langlet, A. Benazzouk, M. Queneudec, Feasibility study of lightweight cement composite containing flax by-product particles: Physico-mechanical properties. Cem Concr Comp (2008) 30 (11): 957-963.
[30] N. El Hajj, RM. Dheilly, Z. Aboura, ML. Benzeggagh, M. Queneudec, Procédé de fabrication des composites 100% végétaux : Effet de la granulométrie des étoupes de lin et de l'ajout des bios liants. Actes des 16èmes JNC, Toulouse, 10-12 June 2009.
[31] A. Bouguerra, A. Ledhem, F. de Barquin, R.M. Dheilly, M. Quéneudec, Effect of microstructure on the mechanical and thermal properties of lightweight concrete prepared from clay, cement, and wood aggregates. Cem Conc Res (1998) 28 (8): 1179-1190.
[32] A. Govin, Aspects physico-chimiques de l'interaction bois-béton - Modification de l'hydratation du ciment par le bois. Doctoral thesis, Université de Saint-Etienne, 2004.
[33] P. Coatanlem, R. Jauberthie, F. Rendell, Lightweight wood chipping concrete durability. Constr Build Mater (2006) 20: 776-781.
[34] K.E. Semple, R.B. Cunningham, P.D. Evans, The suitability of five Western Australian mallee species for wood-cement composites. Ind Crop Prod (2002) 9: 89-100.
[35] P. Turgut, Cement composites with limestone dust and different grades of wood sawdust. Build Env (2007) 42 (11): 3801-3807.
[36] V. Nozahic, S. Amziane, Influence of sunflower aggregates surface treatments on physical properties and adhesion with a mineral binder. Composites Part A: Applied Science and Manufacturing (2012) 43, (11): 1837-1849.
[37] P. Monreal, LB. Mboumba-Mamboundou, RM. Dheilly, M. Quéneudec, Effects of aggregate coating on the hygral properties of lignocellulosic composites. Cem Concr Comp (2011) 33: 301-308.
[38] J. Khedari, B. Suttisonk, N. Pratinthong, J. Hirunlabh, New lightweight composite construction materials with low thermal conductivity. Cem Concr Comp (2001) 23 (2): 65-70.
[39] S. Charoenvai, J. Khedari, J. Hirunlabh, C. Asasutjarit, B. Zeghmati, D. Quenard, N. Pratintong, Heat and moisture transport in durian fiber based lightweight construction materials. Sol Ener (2005) 78: 543-553.
[40] SR. Karade, M. Irle, K. Maher, Influence of granule properties and concentration on cork-cement compatibility. Europ Wood Prod (2006) 64: 281-286.
[41] T. Le Ngoc Huyen, M. Queneudec T'Kint, C. Remond, B. Chabbert, R.-M. Dheilly, Saccharification of Miscanthus x giganteus, incorporation of lignocellulosic by-product in cementitious matrix. Com Rend Bio (2011) 334: 837.e1-837.e11.
[42] M. Chabannes, J.C. Bénézet, , L. Clerc, E. Garcia-Diaz, Use of raw rice husk as natural aggregate in a lightweight insulating concrete: An innovative application. Constr Build Mater (2014) 70: 428–438.
[43] J. Pinto, B. Vieira, H. Pereira, C. Jacinto, P. Vilela, A. Paiva, et al. Corn cob lightweight concrete for non-structural applications. Constr Build Mater (2012) 34: 346–351.
[44] Terrabitat. http://www.terrabitat.fr/documentation/les-techniques/34-mur-terrepaille, Accessed May 2016
[45] A. Sellami, M. Merzoud, S. Amziane, Improvement in green concrete mechanical properties by treatment of the vegetables particles. Constr Build Mater (2013) 47: 1117-1124.
[46] P. Monreal, LB. Mboumba-Mamboundou, RM. Dheilly, M. Queneudec, Evaluation de l'efficacité des traitements physicochimiques sur les performances mécaniques des bétons lignocellulosiques confectionnés à partir de pulpes de betterave, Actes du congrès Orgagec'08, Marne-la-Vallée, 27-29 August 2008.
[47] R. Belhassen, S. Boufi, F. Vilaseca, JP. López, JA. Méndez, E. Franco, et al. Biocomposites based on Alfa fibers and starch-based biopolymer. Polym Adv Technol (2008) 114: 313.
[48] M. Krus, T. Werner, T. Großkinsky, G. Georgiev, A new load-bearing insulation material made of cattail. First International Conference on Bio-based Building Materials, ICBBM 2015, Jun 2015, Clermont-Ferrand, France. 2015, 666–673.
[49] M. Krus, W. Theuerkorn, T. GroBkinsky, H. Kunzel, New sustainable And insulating building material made of cattail. Full papers NSB (2014).
[50] A. Kriker, G. Debicki, A. Bali, M. Khenfer, M. Chabannet, Mechanical properties of date palm fibres and concrete reinforced with date palm fibres in hot-dry climate. Cem Concr Comp (2005) 27 (5): 554-564.
[51] J. Khedari, B. Suttisonk, N. Pratinthong, J. Hirunlabh, New lightweight composite construction materials with low thermal conductivity, Cem Concr Comp (2001) 23: 65-70.
[52] HS. Ramaswamy, BM. Ahuja, S. Krishnamoorthy, Behavior of concrete reinforced with jute, coir, and bamboo fibres. Cem Concr Comp (1983) 5 (1): 3-13.
[53] M. Rahim, O. Douzane, A.D, Tran Le, G. Promis, T. Langlet, Moisture properties of rape straw concrete and hemp concrete, First International Conference on Bio-based Building Materials, ICBBM 2015, Clermont-Ferrand, France, 2015, 510-516.
[54] A. De Vecchi, A. Valenza, S. Colajanni, E. Sanfilippo, V. Fiore, A. Lanza Volpe, Evaluation and application of opuntia ficus-indica panel, First International Conference on Bio-based Building Materials, ICBBM 2015, Clermont-Ferrand, France, 2015, 460-466.
[55] A. Sales, SA. Lima, Use of Brazilian sugarcane bagasse ash in concrete as sand replacement, Waste Manag (2010) 30: 1114–1122.
[56] C Juárez, B. Guevara, P. Valdez, A. Durán-Herrera, Mechanical properties of natural fibers reinforced sustainable masonry. Constr Build Mater (2010) 24: 1536–1541.
[57] C. Juárez, A. Durán, P. Valdez, G. Fajardo, Performance 1 of-Agave lecheguilla natural fiber in portland cement composites exposed to severe environment conditions. Build Environ (2007) 42: 1151–1157.
[58] A. Elsaid, M. Dawood, R. Seracino, C. Bobko, Mechanical properties of kenaf fiber reinforced concrete. Constr Build Mater (2011) (25): 1991–2001.
[59] M. Bederina, L. Marmoret, K. Mezreb, MM. Khenfer, A. Bali, M. Quéneudec, Effect of the addition of wood shavings on thermal conductivity of sand concretes: Experimental study and modelling. Constr Build Mater (2007) 21: 662–668.
[60] Bederina M, Laidoudi B, Goullieux A, Khenfer MM, Bali A, Quéneudec M. Effect of the treatment of wood shavings on the physico-mechanical characteristics of wood sand concretes. Constr Build Mater (2009) 23: 1311-1315.
[61] R. Hosseinpourpia, A. Varshoee, M. Soltani, P. Hosseini, H. Ziaei Tabari, Production of waste bio-fiber cement-based composites reinforced with nano-SiO2 particles as a substitute for asbestos cement composites. Constr Build Mater (2012) 31: 105–111.
[62] GHD. Tonoli, MN. Belgacem, G. Siqueira, J. Bras, H. Savastano, FA. Rocco Lahr. Processing and dimensional changes of cement based composites reinforced with surface-treated cellulose fibres. Cem Concr Compos (2013) (37): 68–75.
[63] R. Sudin, RN. Swamy, Bamboo and Wood Fibre Cement Composites for Sustainable Infrastructure Regeneration. J Mat Sci (2006) 4: 6917-6924.
[64] V. Picandet, Characterization of Plant-Based Aggregates (Chapter 2). In: Bio-Aggregate-Based Building Materials: Applications to Hemp Concretes, S. Amziane, L. Arnaud (eds), John Wiley & Sons Inc., (2013): 27-74.
[65] N. Chevanan, AR. Womac, VSP. Bitra, C. Igathinathane, YT. Yang, PI. Miu, S. Sokhansanj, Bulk density and compaction behaviour of knife mill chopped switchgrass, wheat straw, and corn stover. Bior Tech (2010) 101: 207-214.
[66] J. Page, M. Sonebi, S. Amziane, Experimental Investigation on the Performance of Hybrid Hemp-Flax Composite Materials. Proc. 1st Int Conf on Bio-Based Build Mater, S. Amziane, M. Sonebi (Eds.), Clermont-Ferrand (France), 21-24 June 2015, RILEM Publications s.a.r.l., 2015, 243-250.
[67] A. Kashtanjeva, M. Sonebi, S. Amziane, Investigation of the Mechanical Performance and Drying Shrinkage of Hemp Concrete. Proc 1st Int Conf on Bio-Based Build Mater, S. Amziane, M. Sonebi (Eds.), Clermont-Ferrand (France), 21-24 June 2015, RILEM Publications s.a.r.l., 2015, 309-315.
[68] T. M. Dinh, C. Magniont, M. Coutand, G. Escadeillas, Hemp Concrete Using Innovative Pozzolanic Binder, Proc 1st Int Conf on Bio-Based Build Mater, Ed. Amziane, S., Sonebi, M., Clermont-Ferrand (France), 21-24 June 2015, RILEM Publications s.a.r.l., 2015, 265-271.
[69] M. Sonebi, Rheological Properties of Grouts with Viscosity Modifying Agents as Diutan Gum and Welan Gum Incorporating Pulverised Fly Ash. Cem Concr Res (2006) 36 (9): 1609-1618.
[70] L. Arnaud, E. Gourlay, Experimental study of parameters influencing mechanical properties of hemp concretes. Constr Build Mater (2012) 28 (1): 50-56.
[71] Y. Diquélou, Interactions entre les granulats de chanvre et les liants à base de ciment et de chaux : Mécanismes de la prise et propriétés des interfaces formées dans les agrobétons. PhD Thesis, Reims, 2013.

[72] E. Gourlay, Caractérisation expérimentale des propriétés mécaniques et hygrothermiques du béton de chanvre. PhD Thesis, Lyon, 2014.
[73] C. Rode, Moisture Buffering of Building Materials, Report BYG•DTU R-126, ISSN 1601-2917, ISBN 87-7877-195, 2005.
[74] S. Dubois, A. Evrard, F. Lebeau, Modeling the hygrothermal behavior of biobased construction materials. Build Phys (2014) 38 (3): 191-213.
[75] F. Collet, S. Pretot, Thermal conductivity of hemp concretes: variation with formulation, density and water content. Constr Build Mater (2014) 65: 612–619.
[76] F. Collet, M. Bart, L. Serres, J. Miriel, Porous structure and water vapour sorption of hemp-based materials. Constr Build Mater (2008) 22: 1271–80.
[77] F. Collet, J. Chamoin, S. Prétot, C. Lanos, Comparison of the hygric behaviour of three hemp concretes, Ener Build (2013) 62: 294-303.
[78] H. Janssen, S. Roels, Qualitative and quantitative assessment of interior moisture buffering by enclosures. Ener Build (2009) 41 (4): 382-394.
[79] P. Glé, E. Gourdon, L. Arnaud, Acoustical properties of materials made of vegetable particles with several scales of porosity. Applied Acoustics (2011) 72: 249-259.
[80] P. Glé, E. Gourdon, L. Arnaud, Modelling of the acoustical properties of hemp particles. Constr Build Mater (2012) 37: 801-811.
[81] MP. Boutin, C. Flamin, S. Quinton, G. Gosse, Etude des caractéristiques environnementales du chanvre par l'analyse de son cycle de vie. Ministère de l'agriculture et de la pêche, France, 2006.
[82] P. Hellebois, S. Marceau, M. Guéguen, S. Amziane, Influence of wetting and drying cycles on the properties of hemp concrete. 1st Int RILEM Conf on Rheology and Processing of Construction Materials, Paris, 2013.
[83] S. Marceau, P. Glé, M. Gueguen, E. Gourlay, S. Moscardelli, I. Nour, S. Amziane, L. Abdellaoui, Assessment of the durability of bio-based insulating materials. Proc 1st Int Conf on Bio-Based Build Mater, Ed. Amziane, S., Sonebi, M., Clermont-Ferrand (France), 21-24 June 2015, RILEM Publications s.a.r.l., 2015, 200-204.
[84] M. Gueguen, S. Moscardelli, L. Van Schoors, I. Nour, S. Marceau, Study of the microbial development impact on bio-based materials, Proc 1st Int Conf on Bio-Based Build Mater, Ed. Amziane, S., Sonebi, M., Clermont-Ferrand (France), 21-24 June 2015, RILEM Publications s.a.r.l., 2015, 166-169.
[85] M. Sonebi, M., Wana, M., S. Amziane, J., Khatib, Investigation of the Mechanical Performance and Weathering of Hemp Concrete, Proc 1st Int Conf on Bio-Based Build Mater, Ed. Amziane, S., Sonebi, M., Clermont-Ferrand (France), 21-24 June 2015, RILEM Publications s.a.r.l., 2015, 416-421.
[86] Y. Castel, S., Amziane, M. Sonebi, Durabilite du beton de chanvre : resistance aux cycles d'immersion hydrique et sechage, 1ère Conférence EuroMaghrébine des BioComposites, 28-31 March 2016, Marrakech, 2016.
[87] S. Amziane, V. Nozahic, M. Sonebi, Design of mechanically enhanced concrete using hem shiv, Proc 1st Int Conf on Bio-Based Build Mater, Ed. Amziane, S., Sonebi, M., Clermont-Ferrand (France), 21-24 June 2015, RILEM Publications s.a.r.l., 2015, 422-426.
[88] Y. Diquélou, E. Gourlay, L. Arnaud, B. Kurek, Impact of hemp shiv on cement setting and hardening: Influence of the extracted components from the aggregates and study of the interfaces with the inorganic matrix. Cem Concr Comp (2015) 55: 112-121.
[89] D. Sedan, Etude des interactions physico-chimiques aux interfaces fibres de chanvre/ciment. Influence sur les propriétés mécaniques du composite. PhD Thesis, Université de Limoges, 2007.
[90] RD. Toledo Filho, F. de Andrade Silva, EMR. Fairbairn, J. de Almeida Melo Filho, Durability of compression molded sisal fiber reinforced mortar laminates. Constr Build Mater (2009) 23: 2409-2420.
[91] H. Viitanen, J. Vinha, K. Salminen, T. Ojanen, R. Peuhkuri, L. Paajanen, K. Lähdesmäki, Moisture and bio-deterioration risk of building materials and structures. J Build Phys (2010) 33: 201-224.
[92] R. Walker, S. Pavia, R. Mitchell, Mechanical properties and durability of hemp-lime concretes. Constr Build Mater (2014) 61: 340-348.
[93] N. Cherrett, Ecological Footprint and Water Analysis of Cotton, Hemp and Polyester. Report prepared for and reviewed by BioRegional Development Group and World Wide Fund for Nature – Cymru, 2005.
[94] Pervaiz M., Carbon storage potential in natural fiber composites. Resources, Conservation and Recycling (2003) 39: 325-340.
[95] R. Rhydwen, A model for UK hemp cultivation and processing to supply the building industry with hurds for hemp and lime concrete and fibres for insulation bats, with the ethos of environmental protection as a priority. MSc. Thesis. University of East London, 2006.