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Assessment of distilled lavender stalks as bioaggregate for building materials: Hygrothermal properties, mechanical performance and chemical interactions with mineral pozzolanic binder

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HIGHLIGHTS

- Distilled lavender straw is characterized as a potential building bioaggregate.
- Lavender-based composite exhibits promising thermal and hygric performances.
- Lavender based composite presents very weak mechanical performances.
- Lavender extractives disturb the setting and the hardening of the pozzolanic paste.

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ABSTRACT

The building construction sector has a major impact on sustainable development, mainly in terms of raw material use, greenhouse gas emissions and waste production. Studies on alternative materials are nowadays clearly a priority to improve energy consumption and optimize waste management. Bio-based construction materials could take up this environmental challenge. Bio-based aggregates are renewable, they are mainly produced locally and they constitute an important way to store carbon dioxide. Most of the time, these bio-based aggregates are sub-products from local industries located near the factories producing building materials. Their use thus contributes largely to a decrease in the waste produced.

Moreover, many studies have underlined the very interesting hygrothermal properties of bio-based materials, although some interactions of the bioaggregates with their surrounding environment have to be considered. Various authors have shown that cement (e.g. Portland cement), used as a mineral binder sometimes presents compatibility problems with bio-based aggregates, which can impact the setting and hardening processes of the binder.

Among the several bioaggregates that can be considered, the waste derived from the production of essential oils is becoming an important issue. Essential oils are increasingly used in industrial countries today, mainly in medicinal or beauty products for their aromatic, medicinal and biological properties. These oils are primarily obtained by distillation of aromatic and medicinal plants. The effectiveness of these industrial and traditional transformations is very low, about 1% by mass, and this leads to large amounts of solid and liquid waste. The processing of these waste materials is inexistent in some countries like France, so waste constitutes a real obstacle to the development of this industrial sector.

The objectives of this work are to determine the physical characteristics of a specific aromatic and medicinal plant residue (lavender straw) and the performances of a composite including this straw in the form of bioaggregates within a pozzolanic matrix previously designed by combining metakaolin with slaked lime. The characterization of lavender aggregates was conducted through Scanning Electron Microscope observations and their bulk density, water absorption capacity, bulk thermal conductivity and particle size distribution were assessed by an image analysis method. The thermal conductivity, water vapour permeability, moisture buffer value and mechanical properties of the composite were assessed.

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Finally, a study was conducted in order to understand the impact of lavender aggregates on the hydration mechanisms of the pozzolanic binder. Model pastes were elaborated with a solution obtained by soaking lavender particles in demineralized water for 72 h and then filtering. The properties of the pastes were compared with those of neat pozzolanic paste.

The setting time, hardening mechanisms (followed by X-ray diffraction and thermogravimetric analysis) and mechanical performance of the pozzolanic matrix were clearly influenced by the lavender extractives.

1. Introduction

The building construction industry has a major impact on sustainable development, mainly in terms of the use of raw material, greenhouse gas emissions and waste production. The civil engineering sector worldwide consumes about 50% of raw materials coming from the soil, and produces about 40% of all waste due to human activities [1]. Studies on alternative materials are clearly a priority nowadays, to reduce energy consumption and optimize waste management.

Bio-based construction materials could take up this environmental challenge. Bio-based aggregates are renewable; they are mainly produced locally and they constitute an important way to store carbon dioxide. Most of the time, these bio-based aggregates come from local agricultural activities located near the production sites of building materials. As sub-products of these industries, their use helps to decrease the quantity of waste produced. Many solutions to obtain new bio-based construction materials are already being tested by laboratories and industrials: specific plants (flax, hemp) are cultivated and some plant parts that are not sold as agricultural products are recovered (corn cobs, sunflower stems, straw).

Many studies have underlined the great interest of the hygrothermal properties of bio-based materials [2–5]. The thermal conductivity of many materials is clearly reduced by the use of bioaggregates, while moisture exchanges with the air around the material can be very useful to control indoor air humidity and can enhance indoor comfort.

Among the several bio-aggregates that can be considered, the waste derived from essential oils appears to be an important source. Essential oils are more and more used in industrial countries today, mainly in medicinal or beauty products for their aromatic, medicinal and biological properties. The world production of lavender oil is 200 tons per year, and France produces 40 tons per year with 3500 ha of crops. The world production of lavandin oil is about 1000 tons per year with France representing 90% of the production distributed over 16,000 ha [6]. These oils are primarily obtained by distillation of aromatic and medicinal plants. The efficiency of the industrial and traditional transformations of such plants is very low, about 1% in mass, and leads to a great amount of solid and liquid waste. No processing is foreseen for these waste materials in some countries like France, so they constitute a real obstacle to the development of this industrial sector.

Valorization of such natural waste appears unavoidable if we are to decrease the impact, on greenhouse gas production for example, of these productions linked to aromatic and medicinal plants. However, aromatic and medicinal plant residues are not yet valorized in the construction field, where they could constitute a very important source of savings in terms of material, and increase profits.

The use of bioaggregates instead of natural or artificial mineral aggregates helps to reduce the environmental impact of constructions. Use of these bioagreggates is growing in the building sector (biobased buildings), where hemp shives, flax shives, corn cobs, sunflower stems, palm fruit shells, etc. are already used in aggregates, which are generally obtained through mechanical processing.

Nevertheless, some problems directly linked with the use of bioaggregates clearly appear in the literature. Experiments concerning the management of water in hemp concrete mixtures have shown that the strong power of absorption of these aggregates leads to a problem of compatibility with cement. When water is present in the usual proportions, bioaggregates tend to monopolize it, leading to poor hydration of the composite mixture because water is in short supply. On the other hand, if the water ratio is increased in the mixture to avoid this problem, the consequence is a very long drying time hardly compatible with conventional modern construction rates. The production of precast blocks would reduce the importance of drying time. In this context, previous works [7,8] led to the development of hemp concrete blocks produced by a vibrocompaction process at industrial scale, with good thermal, hygric and mechanical properties. However, as the regional supply of hemp shives was interrupted, this production was impacted. Due to their wide availability, lavender stalks constitute a good candidate to replace hemp shiv. The objectives of this work are to determine the physical characteristics of the residues of this particular aromatic and medicinal plant (lavender) and to study the mechanical, thermal and hygroscopic performances of a composite using them as bioaggregates in association with a pozzolanic binder. In the last part of the paper, the chemical interactions between lavender extractives and this mineral binder will be explored.

2. Materials and methods

2.1. Materials

2.1.1. Mineral binder and admixtures

Metakaolin (MK) is a pozzolanic admixture produced by flash calcination of kaolinite at 700 °C. It is mainly composed of quartz and silicon and aluminium oxides with an amorphous silico-aluminate mineralogical form. The latter phase is responsible for the pozzolanic activity of metakaolin, which reacts with calcium hydroxide ($Ca(OH)_2$) to form C-S-H gel, calcium aluminate hydrates (C_4AH_{13} and C_3AH_6 – hydrogarnet) and calcium alumino-silicate hydrates (C_2ASH_8 – straetlingite) [9].

To formulate the binder, metakaolin was combined with a commercial slaked lime produced by the calcination at 1000 °C and slaking of a limestone. Its major mineralogical ingredient, making up around 92% of the material, was $Ca(OH)_2$.

In this study, two different admixtures were used to improve the performance of the composite at early age: potassium sulfate and glycerol carbonate. The potassium sulfate (PS) used in this study is produced by VWR BDH Prolabo. It is a chemical activator that encourages ettringite formation (Eq. (1)) and accelerates the pozzolanic reaction, leading to an improvement in strength at early ages [10,11].

$$2Al(OH)_4 + 3SO_4^{2-} + Ca^{2+} + 4OH^- + 26H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O \quad (1)$$