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Multicriteria analysis demonstrating the impact of shiv on the properties of hemp concrete

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HIGHLIGHTS

- A multicriteria analysis was used to classify the types of shiv into three groups.
- Three mechanical responses were demonstrated for the compression test on hempcrete.
- Large specific surface area of shiv is the source of weak binder–aggregate bonding.
- The shiv which optimises all characteristics, offers concrete with good performance.
- A multicriteria analysis allows also to classify hempcrete into three groups.

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ABSTRACT

The shiv derived from the shredded stem of the hemp plant [1], when mixed with a mineral binder and water, produces hemp concrete (or "hempcrete"), which is considered as an eco-material because of its remarkable environmental properties (favourable CO_2 balance, easy management and disposal at the end of the product life, etc.) [2]. However, much like any agricultural product, its quality may be affected by the soil where the hemp has been grown, the weather conditions, and a variety of other factors. As these parameters are rather variable, the produced plant matter tends to be somewhat irregular, which can hamper the development of this type of building solution. The study at hand tests the characteristics of the hemp (particle size distribution, water absorption capacity, etc.), to assess the impact of the variability of these factors on the performance of the hempcrete made with the shiv. To begin with, the thirteen types of shiv used in the study were compared by multicriteria analysis, and then classified into three different groups.

Next, nine types of shiv were selected, so that each of the three groups was represented. In identical conditions (i.e. the only variable being the type of shiv), specimen of hempcrete were made up in the lab for experimentation. The aim here was to validate the results of the study characterising the different types of shiv. The results show that there are three main types of mechanical response when the hempcrete is subjected to a compression test, where the material behaviour is characterised by small, medium or large strains. The large specific surface area of shiv is known to be responsible for weak binding at the interface between the binder and the plant particles, leading to total failure of the test piece. In addition, its high water absorption capacity, which is the likely cause of the "false set effect" associated with the elongated form of the particles, is identified as being responsible for the high rates of deformability found. It should be noted that in the latter case, the specimens behave like a succession of layers, which accounts for the significant levels of strain.

By multicriteria analysis of the results for the hempcrete specimens, we found that they can be also classified into three groups, matching the three detected by the multicriteria analysis of the types of shiv from which they were made. Unlike the previously published literature, this study leads to the conclusion that shiv types with small particle sizes and high water absorption capacities do not produce the best performance.

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1. Introduction

Owing to its high degree of porosity, hemp concrete is sensitive to a number of factors, which can be classified into three categories: (1) methods of manufacture or installation [3–5]; (2) methods and techniques for measuring the properties of the hempcrete [6–8]; and (3) nature and quantity of the components [9–13]. In light of the objectives of this study, and in view of the three categories mentioned above, we shall focus on the nature and quantity of the components – more specifically, the shiv.

Certain properties of the shiv have been identified as being responsible for problems observed during the setting and hardening of hempcrete [11,14]. Such problems prevent strong connections between the binder and the shiv, leading to poor mechanical performances of the material. These properties are often due to the morphology of the shiv (the particle size) [15,16]; to its composition – in particular, its fibre and dust content [17], to its chemical composition [18,19] or to its water absorption capacity [20].

A literature review concerning the morphological influence of the shiv on the properties of hempcrete shows discrepancies between various results, highlighting the need for further research to shed light on the matter. In a study published in 2012 [15], three types of shiv (N°1 to N°3) – of equal thickness but different widths, lengths and densities – were used. To exclude any influence by the binder, a single type of binder was used: a mixture of 75% aerated lime, 15% hydraulic lime and 10% pozzolana. The test pieces made up with the finest-grained shiv (N°3) exhibit poor strength at 28 days, but much better strength at 4 months, which improves significantly beyond that point. The authors state that shiv N°3 is less porous because its particles are finer than those of the other two samples. Consequently, the CO_2 which is responsible for setting and hardening is less easily diffused, which slows the kinetics of drying of the test pieces, leading to poor mechanical strength in the short term. Conversely, as the particles are fine, they are well coated with binder when the concrete is mixed, which accounts for the better mechanical performances observed in the long term. In conclusion, the use of fine-grained shiv helps improving the hempcrete's long-term mechanical performances. This conclusion is not entirely consistent with the work of Nguyen [21]. Like Arnaud and Gourlay [15], Nguyen also observed the better mechanical performances at 28 days for hempcrete made with larger particles, but noted no significant difference at 90 days. However, the results found by Stevulova et al. [10] are in keeping with Arnaud and Gourlay's [15] results. Note, also, that the study on panels manufactured with binderless hemp shiv demonstrated the improvement of the mechanical properties with smaller particles of hemp [22].

In the work of Stevulova et al. [10], six samples of shiv (two original samples and four fractions), with different particle sizes, were studied in the same conditions (same binder, formulation, etc.). The results at 28 days show that an increase in the average length of a particle decreases the compression stress. At the same time, the compression stress differs depending on the origins of the used shiv. On the latter point, the authors merely stated that the origin of the shiv can impact the mechanical behaviour of hempcrete, but do not go into further detail. The origin is not, in itself, a quantifiable parameter, which makes it difficult to take it into account. However, it is possible to study its impact on the irregularity of the hempcrete, based on other characteristics such as, say, the chemical composition or water absorption. This, as we shall see later on, is the reason why other characteristics are taken into account in our study. In spite of the contradictions, many authors agree that decreasing the particle size leads to improvements in the mechanical performance.

Consequently, for this study, we consider the assumption that it is better to minimise the particle size

Besides the size of the shiv particles, the fibre content can also influence the final properties of hempcrete. Chamoin [23] looked at two types of shiv: one without fibre (F1) and the other containing fibres (F2). The production conditions were exactly the same – in particular, the nature of the binder, the proportion of binder to shiv and the method of installation. The only difference lies in the amount of water used, as F2 requires more mixing water. The author concludes that F1 has better mechanical performances, and thus the use of F2 affects the setting of the binder. Indeed, the large amount of mixing water required by the fibrous shiv means that the binder is diluted, lessening its mechanical strength when set. Finally, the use of F2 increases the hempcrete apparent density, but noticeably decreases its performance under compression.

In an earlier study [21], it was found that fibres helped to preserve the structure of the test specimens, preventing them from collapsing. *A priori*, this would seem to indicate an improvement of the mechanical performance. However, according to the analysis of the experimental results, this is not the case: the test specimens made up with fibrous shiv exhibit low values of compression stress and Young's modulus.

The author accounts for these results by saying that there is greater inter-granular porosity with the hempcrete made from fibrous shiv. In addition, the adhesion between the fibres and the binder may be poorer than that between the shiv and the binder, which further degrades the mechanical performance. Also, De Bruijn [24] observed no difference in terms of mechanical behaviour, between the use of fibrous and pure shiv.

In view of these contradictions, and in light of the non-fibrous nature of the shivs used in our study, we assume that fibres do not have significant impact on the mechanical performance of the hempcrete. Therefore, fibre content is not taken into account.

Recently, studies have been carried out to demonstrate the effect of the chemical compounds of shiv on the properties of the resulting hempcrete [11,14]. When the shiv is put in water, molecules which are weakly bound to the cell walls dissolve; these water-extractible compounds are called "lixiviates". When the hempcrete is being made, they combine with the mixing water needed to hydrate the cement, which can affect its setting and hardening. It has been shown that these lixiviates are made up primarily of ash, lignin, sugars, proteins and other compounds which have to be identified. The ash may derive from the minerals making up the plant, or from dust which has not been entirely eliminated during the defibration process [25]. The shivs used contain lignin in varying quantities, but lignin has a significant impact on the time taken for the cement to set [26]. Most likely, it is that lignin content which is to blame for the phenomenon of "**false set**" observed during this study. In conclusion, the nature of the water-extractible compounds depends on the type of shiv. They greatly delay the setting, and hence have a negative impact on the performances of the hempcrete.

If lime is considered, there are a number of elements missing from the literature regarding the impact of the chemical compounds on the properties of hempcrete.

Therefore, the chemical compound aspect is not taken into account in the context of this study – especially as the binder used is lime.

Although the impact of shiv on hempcrete properties has been studied [7,10,15,21], where conflicting results are strongly observed, we can highlight the interest and the need to investigate this issue further.

The first step in conducting an in-depth study is to characterise the type of shiv on the basis of several properties at once. The characteristics taken into account are: the bulk density, the water absorption capacity and the particle size distribution (PSD). Using