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Improving the Behaviour of Green Concrete Geopolymers Using Different HEMP Preservation Conditions (Fresh and Wet)

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Abstract: This paper evaluates a type of geopolymer concrete that uses hemp fibres as a natural aggregate due to the various advantages offered by these woody materials. These advantages include ease of cultivation and processing and their use in the essential structure of concretes used for green construction purposes. The sampling study was prepared using an environmentally friendly inorganic binder, based on geopolymerization reactions (Si-Na). The improvement in the hemp aggregate using two different preservation methods (fresh and wet) was assessed. The type of conservation enables anaerobic reactions to take place in the structure of the hemp, in such a way as to modify the proportions of the organic compounds contained in the hemp and the morphology of the fibres. It also encourages the proliferation of cellulose nanofibrils (CNC), which enhance the mechanical results, improving plasticity and thixotropy. The hempcrete studied in this paper could be a good alternative material for sustainable, environmentally friendly construction, as much less CO_2 is emitted during the production process in comparison with conventional concrete. Using wet-preserved hemp means that less water must be added to the mix during preparation of the concrete. This also helps reduce production costs, and by extension, the cost of the final product.

Keywords: sustainable materials; concrete geopolymer; fresh and wet preservation; hemp fibres; circular economy

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1. Introduction

One of the basic principles of the circular economy in the building materials sector is that new solutions and alternative proposals must be implemented to eliminate the negative impacts on the environment of certain building materials [1–3]. Normally, these tend to involve high energy consumption and non-renewable resources [4–8]. One of the clearest examples are products made of Portland cement, whose manufacturing process involves high CO_2 emissions [9]. New research has demonstrated that one of the best solutions involves using geopolymer compounds (in this case made of alkalis and strengthened with fibres) together with more sustainable new technologies [10,11].

Nowadays, given the increase in competition in the building materials market, the need to develop environmentally friendly products is becoming the main focus of the latest trends in design [12].

By definition [13,14], hempcrete, a concrete prepared with lime and hemp, is a light concrete which uses hemp hurds or shivs (waste products from hemp fibre production) as an aggregate, together with a lime-based binder, which is more compatible than cement [15]. The high proportion of materials of biological origin means that hemp lime is a net absorber of carbon dioxide with an essentially sustainable production system [16,17].

Research confirms the strong impact that the compositional and structural conditions (hemp–lime ratio, proportion of binder, porous structure [18], disposition of the fibres [19]) can have on the hempcrete's main properties, as can the way it is placed in the building and other manufacturing conditions [13]. Researchers have also found that hemp concrete has low density [20] and good thermal and acoustic insulation properties [21,22] due to its porosity and low density. It is also known for its good hygrothermal properties [23] and its high water-vapour permeability and sorption properties [23–25]. This enables it to passively regulate the humidity in a built environment, in that it can absorb relative humidity or indeed return it to the environment, in the event of any excess or lack in the comfort ambience of the room [26,27]. According to [28], it is precisely hempcrete's absorbent power that enables it to moderate the daily variations in relative humidity and guarantee the good quality of indoor air. It also shows great capacity to resist fire, mould, and fungi [14] and is known to be a non-allergenic material, as no allergic reactions are related to its use. It can therefore be viewed as a material that respects the health of living creatures [29]. Finally, it has an excellent useful life and low maintenance costs [30]. From the point of view of durability, [15] confirmed that the binder is responsible for the resistance of hempcrete during freeze/thaw cycles, exposure to salt and biodegradation.

For this reason, building materials manufacturers are increasingly replacing cement materials with geopolymers [31,32]. In addition, in recent years, there has been growing interest in the use of natural fibres as a substitute for synthetic fibres [3,8,33]. This option is usually considered to be positive from an environmental perspective because it reduces CO_2 emissions significantly [34–37]. Several studies [37–40] confirm that these natural fibre compounds are suitable for use in a range of different building materials because they have better intrinsic properties (mechanical strength, thermal resistance, low thermal conductivity, etc.), in addition to other positive characteristics that could improve their behaviour as building materials and during their manufacturing process [41].

Also, in this case, the most important advantage is that low temperatures and minimum amounts of water are used during the manufacturing process [3,42–45]. Another benefit of building materials made with natural fibres is that they have lower production costs than those made with synthetic fibres [3,8,38]. Nevertheless, there are also certain disadvantages.

The most obvious disadvantages are low compressive strength and elastic modulus [20], the loss of properties over time due to the problems of biodegradation by UV rays identified in geopolymers made with natural fibres [46], and the dissolution or precipitation of new compounds in the mixes [23]. As a highly heterogeneous and anisotropic material [47], when it is exposed to outdoor climate conditions, dimensional variations [48] and changes in shape, which can also affect its hygrothermal behaviour [49], can appear. Due to its hygroscopic nature, it is especially sensitive to variations in humidity, which cause changes in the volume of its fibres.

The use of natural fibres of this kind has shown how useful they can be in building materials in which the most important characteristics are mechanical strength and thermal and acoustic properties, with similar results to other materials with reinforcement fibres [7,50,51]. Other studies show that adding hemp fibres during the manufacture of geopolymer composites improved the mechanical properties as compared to a geopolymer without hemp [52].

Other authors [53] confirm that when hemp fibres are added to the concrete mix, their extractive molecules spread throughout the water in the mix, slowing down the kinetics of the hydration of the binder. This could alter the properties of the materials; in particular, it could reduce their mechanical resistance [54–56]. Certain mechanisms of interaction between plant molecules and mineral phases have been identified that could explain this result.

Moreover, the addition of hemp fibres changed the structural failure classification from brittle to quasi-ductile. The durability tests on hempcrete blocks and hempcrete render showed that the elements maintained their good performance in terms of mechanical properties and permeability to water vapour [57]. Hydraulic binders also improved mechanical properties and resistance to frost [58].

Finally, several studies [3,59–61] have demonstrated that industrial hemp fibre has great potential for use in building materials and is recognized as one of the most resistant, most rigid natural fibres available worldwide. In order to limit the effects of the hemp on the hydration of the binders [62–65], other authors propose adapting the formulation of the binders and their additives [66–69].

These issues are resolved and the final performance is improved using pre-treatments [70–77]. In recent years, fibre plant cultivation has increased all over the world [78,79]. Looking specifically at hemp, this is due to the fact that it does not contain herbicides and is resistant to insects and disease. Various different parts of the plant are valued positively, and it has a simpler recycling process than other plant types. As has been pointed out in [80], each tonne of hemp cultivated is capable of reabsorbing up to 1800 kg of CO_2.

Other important issues include the selection of the raw material and the processing procedure, in which the fibres that contain leaves, stems, and cores offer special advantages, as several authors have confirmed [75,81,82]. In regards to materials made of hemp fibres, cultivation and harvesting conditions are of great importance. Numerous studies [83–86] confirm that these processes cause enormous variability in the conditions of the natural fibres and in the properties of the compound materials, affecting chemical composition (proportion of hemicellulose, lignin, and cellulose) and structural features (shape, size, etc.).

If we turn to the effects of the chemical composition of the fibres, it is well-known that the improvement that cellulose nanocrystals have brought about in different sectors such as energy, water purification, the automotive industry, biomedicine, and biocomposites [87–89] is due to their excellent chemical, mechanical, and thermal properties along with other benefits such as non-toxicity, surface functionality, easy modification, and sustainability.

Furthermore, several recent studies have highlighted that the generation of cellulose nanocrystals from the most common fibres improves the behaviour of certain building materials [90–93]. In the specific case of hemp fibres, [94–96], a review of the literature confirms that the chemical pre-treatment of the fibres shows the great potential that the modification of nanosilica and CNCs in geopolymer materials has for improving their mechanical properties. These improvements are very useful but can also be a source of problems if not used properly.

As for the conditions in which the fibres are preserved and how this affects their behaviour, several studies [97,98] indicate that the climatic conditions entail certain risks. For this reason, other studies [99–101] propose simplifying the harvesting process to try to reduce the problems caused by the weather conditions at harvest time. Recently, a new harvesting technique has been developed that is unaffected by climate conditions. This technique involves a two-stage process in which the hemp is harvested and then preserved in wet storage in anaerobic conditions [102,103], during which natural fermentation takes place. This causes changes in the content of the hemp (proportional composition of the different elements) while maintaining the positive qualities of the fibres [82,104].

In this paper, the behaviour of geopolymer hempcrete with varying compositions in different states of preservation was studied. The main goal was to find out whether the preservation of the hemp fibres in different forms during the storage process affects their behaviour when used in building materials.

Our second objective was to demonstrate that the use of this type of green material can reduce costs, as it has better qualities and can be stored in a humid state, reducing costs when growing conditions are not adequate or when it cannot be grown in the native area. All these factors involve the optimization of natural resources. To this end, the environmental sustainability assessment can identify the impact of different farming practices (choice of harvest time, cultivar, conservation conditions, etc.) on industrial hemp cultivation to produce fibres that can be used in building materials. This research seeks to demonstrate that many products can have circular value if the conservation conditions are studied and possible new uses are identified. It is also important to remember that circular economy models can help provide a huge competitive advantage, not only in terms of their objectives but also because they produce more value from available resources than traditional production and consumption models [105,106].

2. Materials and Methods

In this research, the samples were prepared with an organic hemp binder and inorganic materials. The materials used as the organic binder were from the Fedora 17 variety of hemp. It had two different states of conservation (freshly harvested hemp (H) and hemp preserved wet in anaerobic conditions for six months (A)). The inorganic materials were clay, sodium silicate, glass powder, and sodium hydroxide. In both cases, after harvesting, the hemp was stored in hermetically sealed plastic containers. Both types of hemp (recently harvested and wet-preserved shredded hemp) were frozen until the different experiments required for this research were conducted.

In order to obtain the shiv, the hemp plant is subjected to a mechanical grinding process (forage harvester) in which the stem is separated from the rest of the plant and later cut up into pieces up to 50 mm long. It is then pressed and packaged with silage films to remove any oxygen and prevent the degradation of the cellulose during the wet storage period.

When the freshly harvested hemp is compared with the hemp preserved in anaerobic conditions for six months, several changes can be observed in the pH and in the content of the metabolic products due to the metabolic activity of anaerobic bacteria (Table 1).

Table 1. Proportion of structural polymers, content of metabolic products and pH in freshly-harvested (H) and anaerobic wet-preserved hemp (A). Data taken from [107].

Metabolic Products	Freshly Harvested Hemp (0 Months) H (%)	Anaerobic Wet-preserved Hemp (6 Months) A (%)
Cellulose	57.25	59.54
Hemicellulose	13.25	11.40
Lignin	9.84	8.51
Alcohols	1.29	1.03
Lactic acid	0.76	0.6
Total acids	1.34	2.32
pH	7.62	5.87

In particular, we found that in the wet-preserved samples (A), there was a decrease in the percentage of lignin (13.5%) and hemicellulose (14%), and an increase in cellulose compound (5%) as compared to the freshly harvested samples (H). There was also a reduction in alcohols (20%) and lactic acid (21%). Total acid content increased sharply (73%).

Finally, we observed that after the 6-month preservation period (A), there was a 23% reduction in pH, a finding that confirms, in line with [38], that wet preservation increases the total acidity of hemp.

Considering that a higher content of fine particles and/or dust in the fibrous material can have a negative effect on the strength properties of the manufactured materials [68,69], a detailed analysis of the hemp particles of the material (with both ways of preservation, H-A) was performed using the Fibre Shape image analysis system (IST AG, Vilters, Ebnat-Kappel, Switzerland) [108]. This analysis, performed by the Leibniz Institute for Agricultural Engineering and Bioeconomics (ATB, Potsdam, Germany) [107], provides insight into the frequency distribution of fibre width (Figure 1).

As for fibre shape, Figure 1 shows that the thinnest fibres (smallest widths) became even thinner, and the thickest fibres (greatest width) became even thicker. In this respect, over an approximate range of 0.136 to 0.251, a fibre thickening of almost 10 units can be observed from freshly harvested hemp to anaerobic wet-preserved hemp, while in the range of 0.251–2.895 it was almost double. All of this is due to the process of wet storage for six months and the fermentation of the hemp, which brought about a slight increase in the cellulose content (see Table 1).

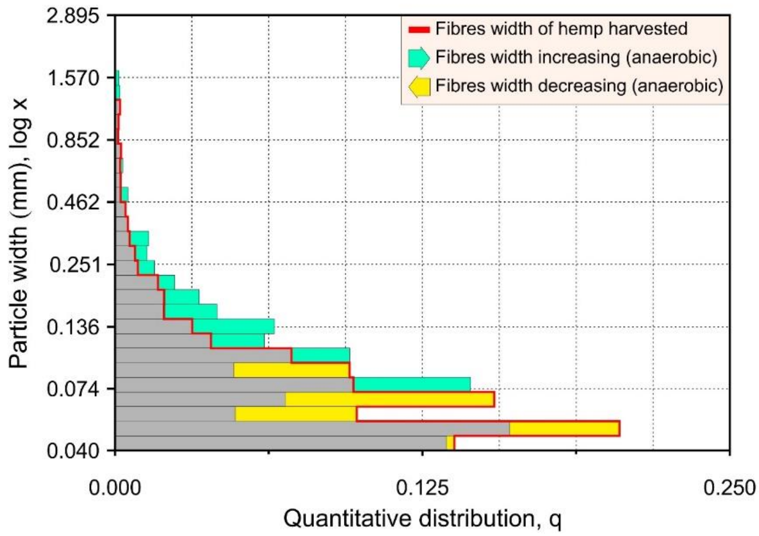

Figure 1. Width and quantitative distribution of the hemp fibres, using FiberShape.

The graphic positioning of the values in the CIELab1976 colour space [109] is presented to enable the best possible differentiation of the differences in chromaticity and luminosity as it is showed in [53,110]. In this research study, colorimetric analysis is of decisive importance to help understand the variations in the chromaticity and the luminosity of the freshly harvested hemp samples, as compared to those preserved in damp anaerobic conditions, which undergo a generalized darkening as a consequence of their storage conditions. Significant variations can also be observed from the yellowish (freshly harvested hemp) to the greenish colour tones (anaerobic wet preserved). This should be taken into consideration in the production of hemp-based products (see Figure 2).

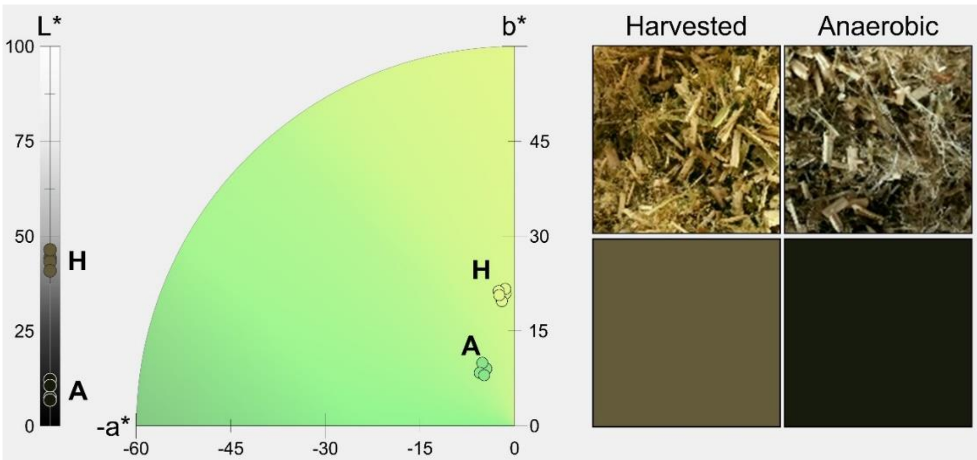

Figure 2. Visual comparison of the two types of hemp (freshly harvested and wet-anaerobic), and their colour representation according to CIELab1976 scheme [109].

The inorganic components used in the samples were studied using X-Ray Diffraction (XRD) and X-Ray Fluorescence (XRF). Their chemical and mineralogical composition can be seen in Table 2 and Figure 3. These are Glass aggregate, which was provided by a Spanish company called Silmin Ibérica (Rubí, Spain). The glass used as an aggregate in the mixture came in the form of a white glass powder with a particle size of 80 to 100 microns. The clay came from a quarry in Guadix (Granada, Spain). Sodium hydroxide (NaOH, in a 5% solution) was supplied by Kremer Pigmente (Aichstetten, Germany) and the liquid sodium silicate (Na_2SiO_3) was supplied by QuiMmipur S.L.U. (Madrid, Spain). For the XRD testing, the raw materials were analysed using a Bruker D8 DISCOVER diffractometer featuring a DECTRIS PILATUS3R 100K-A detector, from the Granada University Scientific Instruments Centre (CIC, Granada, Spain). The Xpowder program [111] was used to determine its composition. For its part, the X-ray fluorescence (XRF) testing was performed using a high-performance compact wavelength dispersive X-ray Fluorescence Spectrometer (brand PANalytical, model Zeltium, Granada University Scientific Instruments Centre, Granada, Spain).

Table 2. XRF analysis of raw materials (wt %). Data normalized to 100% (LOI-free).

Samples	SiO_2	Al_2O_3	Fe_2O_3	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	SO_3	LOI
Glass powder	68.41	1.19	0.2	0.010	3.08	10.27	14.86	0.46	0.09	0.02	0.30	0.98
Sodium silicate	48.08	0.19	0.03			0.03	19.58	0.07	0.01	0.01	0.05	31.78
Sodium silicate + glass powder	50.41	0.33	0.05		0.51	1.31	18.27	0.14	0.02	0.01	0.08	28.73
Clay	53.80	24.52	7.89	0.06	0.92	1.20	1.32	3.42	0.86	0.22	0.09	5.48

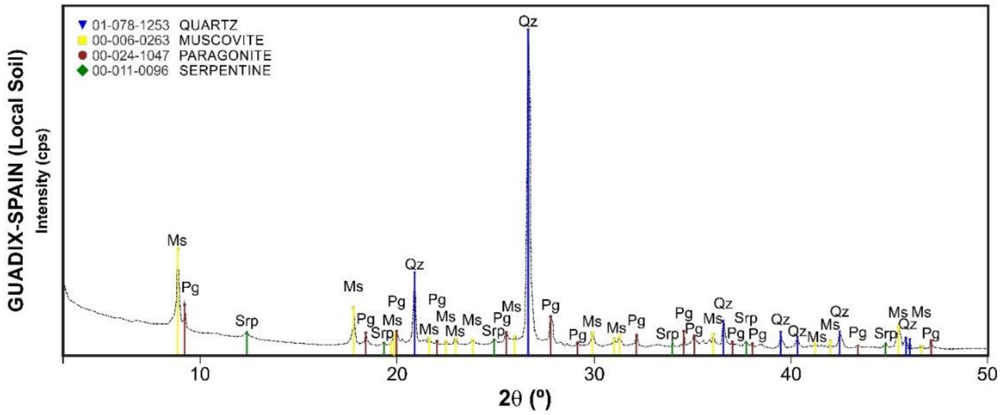

Figure 3. X-ray diffractogram for the clay. Legend: Qz = quartz; Pg = paragonite; Srp = serpentine; Ms = muscovite.

A total of 72 samples was prepared with different formulations. The names and the doses of the groups of test samples are indicated in Table 3. The formulations were given the following abbreviated names: SH1, (Freshly harvested hemp, geopolymer concrete dosage 1); SA2, (anaerobic wet-preserved hemp, geopolymer concrete dosage 2); SH3, (Freshly harvested hemp, geopolymer concrete dosage 3); and SA4, (anaerobic wet-preserved hemp, geopolymer concrete dosage 4). On this basis, all the participating materials without adhesive capacity were considered as aggregates. The amount of additional water used in the SH1, SA2, SH3, and SA4 mixes has been considered in terms of the corresponding percentage of NaOH added. In order to enable us to use them in our experiments, the freshly harvested hemp and the anaerobic wet-preserved hemp were thawed out at T = 22 °C in closed plastic containers 12 h before preparing the concrete for the samples. Prior to mixing, all the materials were stored under the following conditions: T = 22 °C and HR = 70%.

Table 3. Composition and dosage of the samples of geopolymer hempcrete (% volume).

Sample	Freshly Harvested Hemp	Anaerobic Wet-preserved Hemp	Clay (≤1 mm)	Na_2SiO_3	Glass Powder	NaOH
SH1	62.00	——	21.00	12.00	3.75	1.25
SA2	——	62.00	21.00	12.00	3.75	1.25
SH3	66.00	——	10.5	16.00	5.00	2.50
SA4	——	66.00	10.5	16.00	5.00	2.50

In order to prepare the formulation for the geopolymer hempcrete, we began by preparing the mix of liquid components, to which the sieved clay and the hemp would later be added. To this end, the sodium silicate was mixed with the sodium hydroxide

(5% solution in water). The glass dust was then added to this mixture, which was then mixed manually. Once the geopolymer had been homogeneously mixed, the previously sieved (1 mm) clay was added, obtaining a thick suspension to which the hemp was added last of all. The final mixture was then mixed for 3 to 5 min. Two versions were made of each of the three different formulations: one with fresh hemp and the other with 6-month wet-preserved hemp. After removing the moulds, the samples of geopolymer hempcrete were dried on a grid for 12 h at T = 22 °C and HR = 70%. In line with [29,112,113] and previous research [110,114], they were then cured in a drying oven for 24 h at T = 80 °C. After removal from the oven, the samples were placed on a grid where the drying process then continued in the following conditions: T = 22 °C and HR = 70% (see Figure 4).

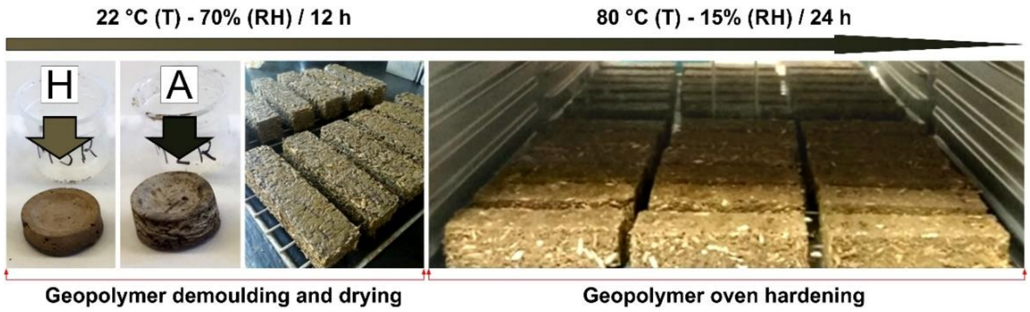

Figure 4. Demoulding, drying, and curing of the geopolymer concrete samples in an oven.

The mineralogy, texture and microstructure of the samples was examined with a scanning electron microscope (SEM) (MODEL Zeiss DMS 950 coupled with Microanalysis Link QX 2000, ZEISS, Jena, Germany) and a polarized optical microscope (MODEL Olympus BX-60, Waltham, MA, USA).

After 28 days, the mechanical resistance of the samples was measured at ambient temperature. Resistance to compression was measured in three 40-mm cube samples, while 40 × 40 × 160 mm prisms were used to measure resistance to bending. These are the standard sizes [115] used in resistance tests. The test was carried out in a universal INSTRON tester (Model 3365) (Instron, Norwood, MA, USA). All the dimensions of each sample were measured (height, length, width and weight), and later, the bulk density was calculated according to standard [116]. The conditions to which the samples were exposed were: temperature = 20 °C and relative humidity = 60%. Finally, the pore structure of the samples was assessed using Mercury Intrusion Porosimetry (MIP).

3. Results

3.1. SEM

The microphotographs shown in the morphological analysis (see Figure 5) reveal several certain differences between the two groups of hemp samples, and in particular the thickening of the hemp fibres.

The top left and right images show the SH1 and SA2 geopolymer concrete, respectively. Swelling of the hemp fibres is indicated with white arrows. The pores are visibly connected, with sizes from 100 μm. The EDX analyses confirm the good composition of the SH1 and SA2 geopolymer concretes. The comparison between the geopolymer made with freshly harvested hemp (SH3) and the one made with anaerobic wet-preserved hemp (SA4) shows a thickening of the hemp fibres in the latter. Finally, image SA2 shows the polymerization typical of materials of this kind due to the composition and the curing conditions (see white arrows). In addition, lumps of silica can be observed in SA4 (white arrows).

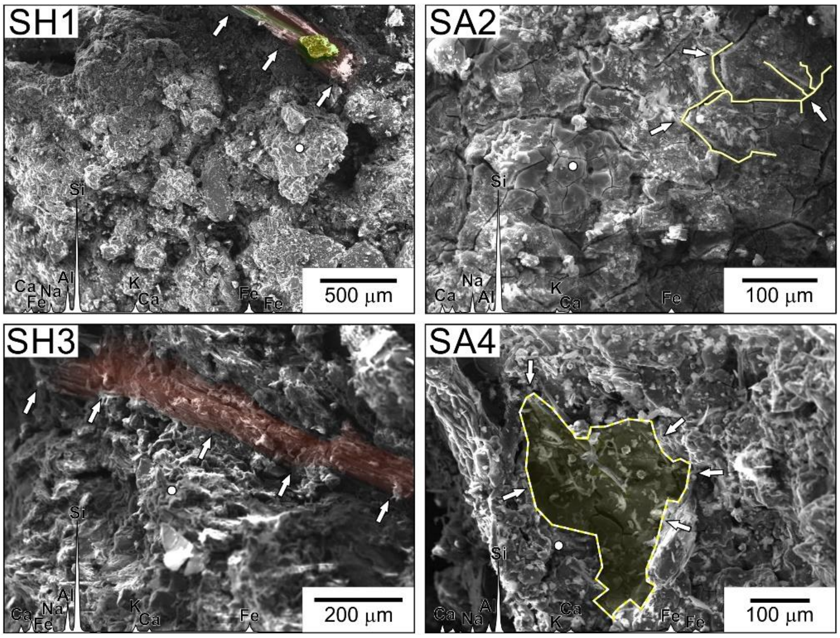

Figure 5. Scanning electron microscopy (SEM) images and EDX analyses.

3.2. Porosimetry

The SH1 and SA2 samples had higher porosity values than samples SH3 and SA4. These higher porosity values are due to the different morphology and distribution of the pores. None of the pores in the samples are closed and the porosity is open. In Figure 6, the trimodal curves show the pore size classification. These curves include very high percentage values (from 81.5% to 91%) for the following pore radius ranges: 100–10 μm, 10–1 μm, and 1–0.1 μm. Pores within these size ranges could be defined as mezzopores [117–119]. Two other types of pores can also be observed: macropores 1000–100 μm, with values between 2.5% and 7%, and micropores, which ranged from 6.5% to 10.5%, for the following size ranges: 0.1–0.01 μm, and greater than 0.01 μm.

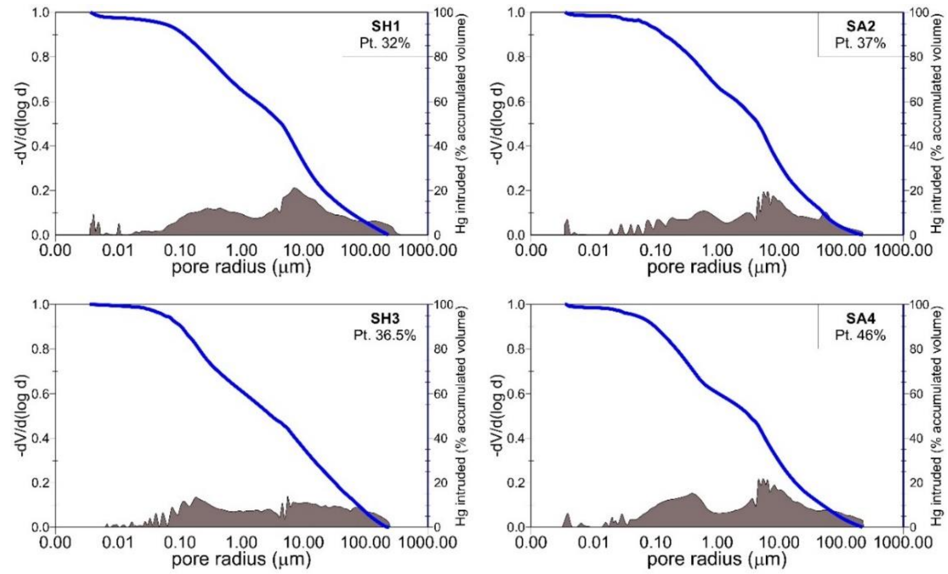

Figure 6. Porosimetric values of the samples studied. The relative volume of intruded Hg is shown in brown. The blue path represents the accumulated volume of intruded Hg (Pt = total porosity).

The percentage of pores in the macropore radius range (r) between 1000–100 μm in anaerobic wet-conserved hemp (A) is half that in freshly harvested hemp (H). In all the samples, more than 90% of the pores are large or medium-sized. The total porosity values are higher, although the freshly harvested hemp (H) has lower values than the anaerobic wet-preserved hemp (A).

3.3. Density

The density of the geopolymer hempcretes varies between 1061 (± 5.75) kg/m^3 and 1112 (± 10.20) kg/m^3 for formulations SH1 and SA2 and between 905 (± 20.85) kg/m^3 and 912 (± 32.12) kg/m^3 for formulations SH3 and SA4. These results are shown in Table 4. The results for freshly harvested hemp indicate that these formulations have lower density values than the anaerobic wet-preserved hemp. This is due to the different clay dosage, as higher ratios were used for the SH1-SA2 sample groups than for the SH3-SA4 sample groups.

Table 4. Density and Mechanical Test results.

Samples	Density (kg/m^3)		Flexural Strength (MPa)		Compressive Strength (Mpa)	
	$\overline{X}$	σ	$\overline{X}$	σ	$\overline{X}$	σ
SH1	1061.35	5.75	2.43	0.42	2.14	0.25
SA2	1112.56	10.20	3.50	0.24	2.57	0.24
SH3	905.57	20.85	2.20	0.22	1.93	0.02
SA4	912.36	32.12	3.74	0.60	2.67	0.12

$\overline{X}$: mean values; σ: standard deviation.

3.4. Mechanical Tests

In the compressive strength tests, the SH1 and SA2 formulations obtained values of 2.14 and 2.57 MPa, while SH3 and SA4 obtained scores of 1.93 and 2.67 MPa, respectively. In flexural strength, SH1 and SA2 obtained values of 2.43 and 3.50 MPa, while for SH3 and SA4, these results were 2.20 and 3.74 MPa, respectively (see Table 4).

It must be emphasized that in all the geopolymer concretes, the results in both resistance tests were lower in freshly harvested hemp (H) than in hemp that was wet-preserved in anaerobic conditions for 6 months. The percentage differences are highlighted. As for the formulations of SH1 and SH3, in terms of compression resistance, the H samples obtained values that were 17% and 28% lower than the A samples. Similar differences of 32% and 42% were obtained in bending resistance. In general, the results indicate that the SH1 and SH3 samples achieve lower mechanical results in resistance to bending and to compression than the SA2 and SA4 samples (See Figure 7).

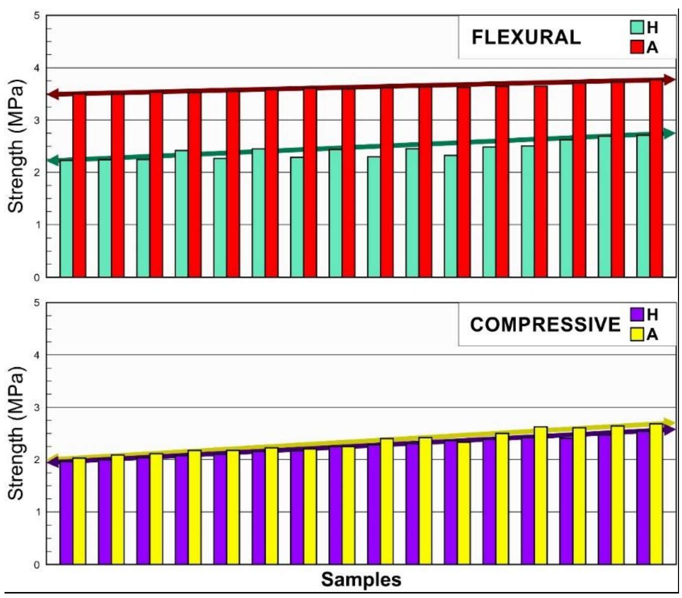

Figure 7. Results of the compressive and bending strength tests.

4. Discussion

When comparing the performance of freshly harvested hemp (H) with that of anaerobic wet-conserved samples (A), the fact that the latter has a lower percentage of cellulose (4%) is the most important reason explaining why the A samples obtained better scores in the mechanical resistance tests.

In this case, their properties improved because of the new structural disposition of the fibres. The results show important differences between the H and A samples of almost 10% in both types of resistance. The research carried out in [82] confirms that the increase in resistance to uniaxial compression and to bending in the anaerobic wet-preserved hemp (A) is due to the existence of cellulose nanocrystals. Along similar lines, [38] indicated that the new conditions of the fibres and the material (a more flexible, lighter, harder biomaterial with very high elasticity modulus and rigidity values) are caused by the increase in the volume of cellulose nanocrystals (CNCs) in the cell walls of certain plant species. Other changes in the fibres can be observed using FiberShape scanning. These include the thickening of the fibres in the anaerobic wet-preserved hemp (after 6 months) compared with the freshly harvested hemp. Moreover, in line with [38,120], the anaerobic wet-preserved hemp (A) is easier to work than the freshly harvested hemp because of the increase in the percentage of cellulose that takes place during the storage process. The changes in the content of hemicellulose and lignin improve the rheology behaviour of the mixtures. The most important changes can be identified by comparing them with the changes that take place when pre-treatments [33] to improve the performance and the properties of the fibres are applied. The results of this study show various benefits in samples conserved in wet anaerobic conditions (A) as compared to the samples of freshly harvested hemp (H).

The relationship between the density and porosity values of the sample groups is dependent on the different proportions of clay used in the formulation of the mixtures. It is also important to remember that there is significant heterogeneity in all the sample groups due to the significant heterogeneity of the hemp and its pore variability.

In general, although the differences between the groups of samples in terms of density and mechanical values are small, the groups of samples with a higher percentage of clay in their dosages have higher densities, as a result of the higher density of the silicates of which they are composed.

This research has also shown that the higher proportion of binder present in SH1 and SA4 formulations causes them to be more resistant to bending than SH3 and SA2, although the difference is small in percentage terms.

It is not clear whether the mechanical strength test values and the density values are related due to the small differences between the different sample groups; what is confirmed is that hemp concrete is highly heterogeneous [47]. However, according to [38,70,82,120–122], the sample groups with anaerobic wet-preserved hemp have better compressive and flexural strength values. Finally, our results show that the doses used in this study led to better mechanical strength results than the dosages used in other similar investigations [123–126].

5. Conclusions

In this paper, we studied the improvement in the behaviour of geopolymers made with wet-preserved hemp in different mixtures. In general, the tests offer positive results and confirm that the hemp conservation method affects the performance of the material. As regards the properties of hemp concrete, we can conclude that the wet anaerobic state of conservation of the hemp improves its qualities as an aggregate, so enhancing the performance of the hempcrete. Specifically, the higher cellulose content in the samples that contained anaerobic wet-preserved hemp improved their mechanical resistance properties. The increases in the percentage of lignin and hemicellulose improved the rheology of the concretes, and by extension, their workability and plasticity. The improvements obtained by anaerobic wet conservation offer important benefits in the use of green concretes of this kind, which in turn offer a range of different benefits in terms of the circular economy.

In addition, in this study, it was confirmed that anaerobic wet preservation reduces the volume of water needed to produce this type of green concrete compared to the formulations used by other authors who used almost thirty times more water in the preparation of their samples [58,124,126]. These results were confirmed by the excellent workability of the samples and the small amounts of water required for mixing. This is obviously an important advantage in areas with limited water resources.

Furthermore, this type of conservation means that the fibres can be preserved in suitable conditions for use at any time of year. This could be very useful in countries where it is difficult to grow these plants due to climate conditions. In this way, the maximum potential of the hemp fibres can be secured, because they can be used in good conservation conditions over a much longer period. Finally, this type of preservation has been considered similar to other pre-treatments required to improve the conditions of the hemp fibres prior to use. Therefore, if these pre-treatments are no longer necessary due to the application of this method, the benefits will be even more significant, firstly, by eliminating the consumption of resources required in these pre-treatments, and secondly, by reducing the hemp production costs and by extension those of the final product.

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