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Elaboration and characterization of lightweight Rammed earth containing hemp particles

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Abstract

The rammed earth or Pisè is one of construction techniques that presents many advantages of availability, inexpensiveness of production costs and potential resources with a very low carbon footprint, and more importantly its low energy consumption. The goal of this work is to investigate the influence of hemp particles on the performance improvement of rammed earth, especially thermal properties, related to the thermodynamic behavior of the building in terms of efficiency and sustainability. The simulations of this preliminary experimentation aim at the physical and mechanical characterization of the soil and hemp mixture. The present work aims to determine along the advantages, the issues that can be produced during the formulation of rammed earth and hemp mixture, also the result of the study would help to the determination of the appropriate sample with the adequate formulation (percentage of Hemp) basing on the results of the used characterization. The challenge is in the use of local materials in building for energy efficiency and environmental, economic and social sustainability.

Keywords: Soil, Rammed earth, Hemp, Characterization, Vegetable particles, Sustainability

1. Introduction

The international mobilization for the climate COP21, organized in Paris, represented a serious warning of the current state of the terrestrial globe and the lack of control of the energy expenditure of consumers. More than 40% of primary energy in the world is consumed by the building sector, mainly for heating or for air conditioning [1]. This consumption tends to increase with density and urban development, despite the aid and new regulations enforce to promote the insulation of buildings. In this context, using earthen construction methods that use soil as raw material could present an alternative solution in order to reduce energy consumption in tertiary building [2]. In fact, in these particular types of buildings integrated with intelligent technologies, the energy requirement is greater than that of civil buildings, so the use of rammed earth with excellent thermal properties, improves the insulation of the

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envelope by reducing the thermal transmittance $U=W/m^2K$ and lowering the energy consumption [3]. It is worthy to notice that choosing rammed earth technique is motivated by multiple reasons:

- The rammed earth is good for the exploitation of the thermal mass,
- It is good thermal insulation due to the thickness of the rammed earth walls (between 30 to 80 cm) [4],
- Has a remarkable compressive strength that can be improve and stabilized with cement and earth walls can be anywhere between 5 to 20 MPa [5]. The aim of the present study is to investigate the influence of Hemp, as vegetable particles, on the technical performance of rammed earth.

It is worth to mention that in the present work, the emphasis is placed on studying a sample of Moroccan soil, used for ages in earthen construction in High Atlas Mountain. Region known by harsh weather conditions.

Our main goal is to improve this eco-friendly sustainable and efficient construction technique in Rammed earth and adapt it to the present time [6]. Before, the characterizations of the raw materials are necessary (soil), to update results already published for this material as well as to get our own database that we are going to use for the creation and development of samples. Noting that the characterization study is conducted to define the intrinsic properties of granular materials, such as morphological, physicochemical, mechanical as well as thermal properties. Therefore, to manufacture, to prepare and correctly to apply a building material for a specific purpose requires a fundamental understanding of raw materials.

2. Geographical location of the study area

The study area is located in the Casablanca region, which is part of the large geological unit known as the Moroccan Coastal Meseta stretching, between the Atlantic and all of the massifs and plains of central Morocco as shown in Fig1.

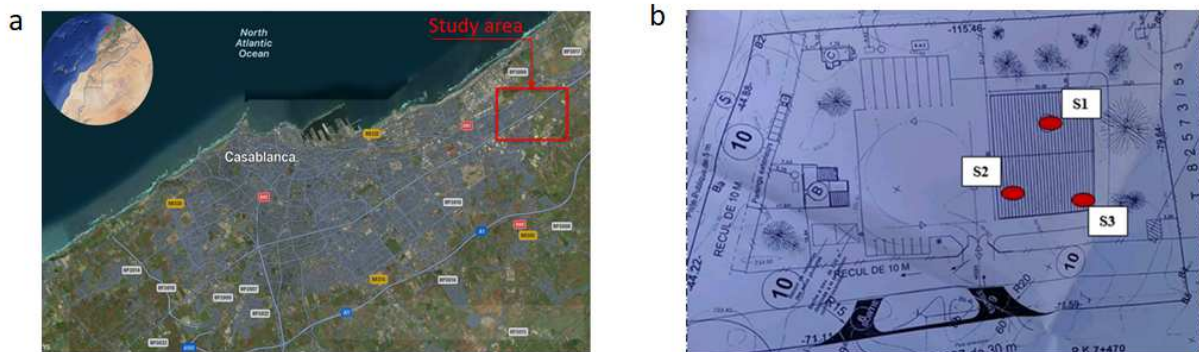


Fig.1 (a) Geographical location of study area, (b) Geographical location of soil samples

The purpose of this procedure is taking a small volume of soil for analysis, which is representative of the entire volume of soil in the study area. The collection of samples has been taken from several point representative of the study area. Notice that the raw material used in rammed earth is usually extracted after the clearing and excavating stage, which consists in removing the top layer of the soil that contains the greatest part of the plant located at a depth proximately ≥ 20 cm. Under such a depth, the optimal soil layer for the construction of rammed earth is found. In order to collect soil samples, we used the borehole investigations, which allows practitioners to determine the nature and location of the different soil/rock layers as shown in Table 1. The soil samples have been collected based on three operations.

We mentioned herein that the three boreholes give the equivalent samples. Only the point S1 was selected as soil samples for the present study. We note that it is located at a depth between 40 cm and 250 cm.

Table 1. Geotechnical sounding depth

Boreholes	Depth	Nature of Soil
Location S1	$0 \leq S1 \leq 40$ cm	Top soil
	$40 \leq S1 \leq 250$ cm	Soil used in rammed earth

3. Preparation of samples

In the aim to study the mechanical influence of Hemp particles on rammed earth, we initiate the tests with two formulation:

- MSC1: 100 % of volume Soil;
- MSC75: 75% of volume Soil + 25% of volume Hemp;
- MSC50: 50% of volume Soil + 50% of volume Hemp;
- MSC25: 25% of volume Soil + 75% of volume Hemp.

Concerning these four formulations, we used the first one as reference to study the influence of hemp particles. However, the others will allow studying the mechanical and morphological influence of Hemp particles on the rammed earth. In order to do so, we calculate the volume necessary to make the sample test. Therefore, we used the following mix designs:

The amount of water was added to the formulation based on the ratio WATER/SOIL, as an example the third formulation (50% V, soil + 50% V Hemp) based on the following ratio WATER / SOIL= 0.13. (Table 2)

After the establishment of the formulations, which will be used for the manufacturing, the preparation and the used of molds, was done according to the European standard EN 196-1. The metal molds have walls at least 10 mm of thickness, 3 horizontal compartments (cross section 40 mm x 40 mm and length 100 mm), we used spatulas and metal ruler for spreading and levelling the mixture. These molds have been oiled, in order to prevent the soil from sticking inside the mold and for ease the removal operation.

The second step consists on the preparation of the mixture using a mixer machine. Firstly, we add the soil with 50% of the overall volume of water, and then we start the mixer at low speed (140 rpm). After 30 ± 1 seconds, we regularly introduce all the soil (in case of formulation MSC1) or we add the hemp particles after the soil-water mixture to reduce the water absorption during the sample preparation process, then we turn up the mixer speed to (285 rpm) for 60 ± 1 seconds.

Table 2. Formulation of the composition

Material	Soil (kg/m ³)	Hemp (kg/m ³)	Water (kg/m ³)
MSC25	557.3	45.2	129.3
MSC50	931	29.2	116.4
MSC75	1009.5	12.3	131
MSC1	1346	0	174

After preparing of the raw material, we started the manufacturing of samples by filling the molds with the raw material that we have been prepared before. The rammed earth manufacturing processes consists on compacting the samples. During this stage, we compacted the molds manually and then we used hydraulic press to ensure an efficient compaction. The pressing force is equal to 13 KN for the prismatic forms and 18 KN for the cylindrical molds.

4. Experimental methods and results

The particle size analysis determines and reports information about the size and range of particles representative of a given soil / hemp samples according to standard NF P 94-057 (Fig.2) This analysis can be performed using a variety

of techniques, but the most suitable one is that determined based on sieve analysis, which consists on sifting the sample through sieves [7].

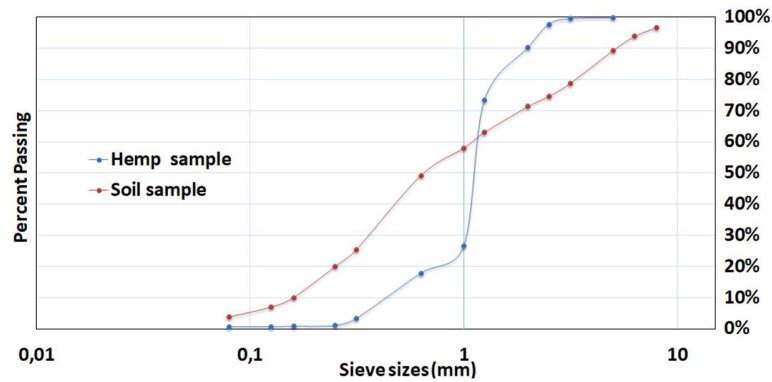


Fig.2 Particle size distribution of hemp and soil samples

Noting that the Fineness Modulus (FM) [NF P18-540] is an experiment that allows to have data based on the addition of the total percentage of the sample of an aggregate retained on each of a specified series of sieves with dividing the sum by 100 [8].

Furthermore, the significance of fineness modulus (FM) is in specifying the proportions of fine and coarse aggregates when designing concrete mixes. This parameter leads to compare the particle ranges between hemp particles and usually sand in traditional concrete.

However, the Modulus (FM) was the favoured tool for quick evaluation of soils and soil blends. The FM is a number used to describe the mean particle size of a soil sample, e.g. an FM of 2 describes a sandy soil and an FM of 7 is a blend too coarse for rammed earth [9].

Table 3. The Fineness Modulus test results

Size sieve (mm)	Cumulative weight (R_n/M_1)x100 (%) Soil	Cumulative weight (R_n/M_1)x100 (%) Hemp
5	10.71	0.23
2.5	25.44	2.28
1.25	36.98	26.70
0.63	50.80	82.13
0.315	74.52	96.62
0.16	89.94	99.22
The Fineness Modulus	2.88	3.07

The concentration of clay particles was determined by the sand equivalent [NF EN 933-8] test, which consists on quantifying the relative abundance clay in soil or impurities liable to affect the quality of the blend.

For example, they are slag, wood particles, fallen leaves, root fragments, etc. A higher sand equivalent value shows that there is less clay-like material in a specimen. In this study, the present soil sample has a sand equivalent value equal to 60.6%, which refers to soil with medium to high clay concentration (Table 3) [10].

Further, to determine the amount of clay particles present in a soil sample we used Methylene Blue test [NF P 94-068], which consists on the presence of the amount of methylene blue adsorbed by a sample of soil (the methylene

blue is preferably adsorbed by clays) [11].

The obtained test gives an MB value of $2.5 \leq 5.6 < 6$. The obtained result highlights that the nature of soil is a loam of medium plasticity. Moreover, moisture content in soil is an important parameter for building construction, known as a fundamental property influencing the behaviour of soils, which can be determined by subtracting the dry weight from the initial weight of soil according to standard [NF EN ISO 181343]. In fact, the presence of humidity in the soil, as a porous structure of different types, depending on the quantity of water, affects its dynamic behaviour connected to the hydraulic conductivity.

Instead, depending on the movement of the water, the behavior of the soil changes according to the capillarity and the speed of water infiltrations, phenomena that highlight the surface condensation, the interstitial condensation etc. in the building. These phenomena of humidity, ascending from the ground also linked to the flows of material and environmental conditions, represent the major cause (about 48.3%) in buildings starting from the foundation structures up to the insulation of the building envelope with indoor pollution [12]. To conduct this test, we used three samples of Hemp and three others of Soil. The first step is to measure their initial weight, which represents the weight in the presence of moisture.

After that, we put the samples in the drying oven at 80°C, and we take them out to measure their dry weight. In this respect, series of measurements are carried out until that the stability of the dry mass is obtained. In this case, the test lasted for 48 Hours until a stable moisture content is achieved (Table 4).

Table 4. Results of moisture continent test

Material	Sample	Moisture content (%)
Soil	1	4.23
	2	3.61
	3	3.16
Hemp	4	11.11
	5	8.61
	6	9.30

The average of Moisture in Soil samples is found about 3.67 %, and the average of Moisture in Hemp samples is 9.67 %.

It should be noted that the vegetable particles such as hemp are very sensitive to water that might influence the shrinkage process of the new formulation of rammed earth material [13]. Thence, their water absorption percentage is determined based on an experimental protocol, which consists on determining the variation in the weight of the material, during its immersion in water, relative to its initial dry mass (Fig.3), The test was carried out until that the saturated mass of Hemp becomes stable. Thereafter, the value of water absorption is calculated using the following formula:

$$A(\%) = \frac{\text{Saturated Mass} - \text{dry mass}}{\text{dry mass}} * 100$$

The average of the water absorption value is 345 %.

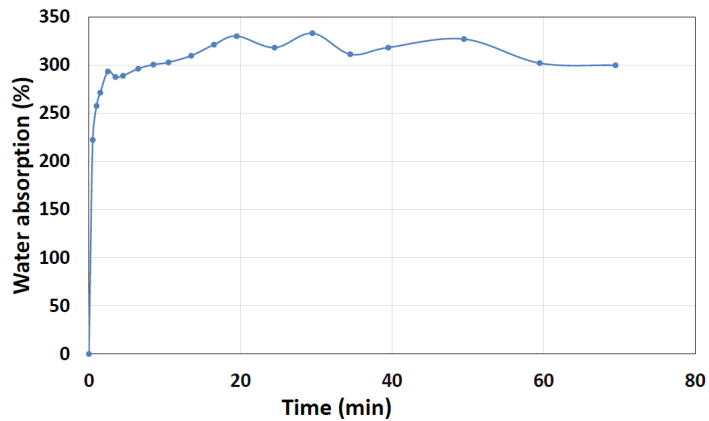


Fig. 3 The variation of absorption versus immersion time

Besides the water absorption influence, the drying effect on vegetable particles is an important factor that should be studied too. In fact, the amounts of water contained in the hemp particles can cause certain anomalies represented as form of separating agent between the particles and the matrix at the interface [14]. In addition, during processing, the evaporation of water creates voids in the materials, which leads to the formation of a network of defects (Fig.4). These anomalies generally lead to a severe reduction in the mechanical performance of the material. In addition, during the consolidation of the blend, based of vegetable particles, the shrinkage processes is fast and can cause significant cracks in the materials.

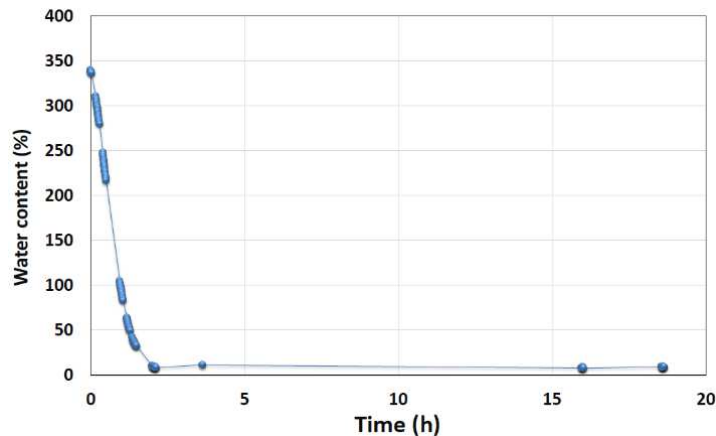


Fig. 4 The drying process on hemp particles

Bulk density, or apparent density, is a property of materials, especially used in reference to mineral components such as (soil, gravel). It is defined as the mass of the many particles of the soil material divided by the total volume that they occupy [15]. According to test standard [NF EN 1936], the obtained results show a bulk density of 105 kg/m³ for Hemp, and for the soil sample is about 1346 kg/m³. After the manufacturing phase, the samples have been placed inside the conservation room, in other to preserve the sample and to maintain their solidification process properly. All samples have kept in regulated hygrometric conditions, with a temperature of (20 ± 2) °C and the humidity of about 97 % (Fig.5) [16].



Fig. 5 Photo showing samples in the environmental chamber

It is however interesting to note that drying is an important part of manufacturing processes in rammed earth construction. The product quality often depends on the drying conditions and efficiency. In the (Fig 6) below, the water content in the formulation of Hemp and Soil, is equal to 21.40%, which represents the double of the water content in the formation of rammed earth made only with Soil. Also, this formulation of Hemp + Soil present a fast drying comparing to the other formulation, owing to the Hemp water absorption properties that is equal to 345 %.

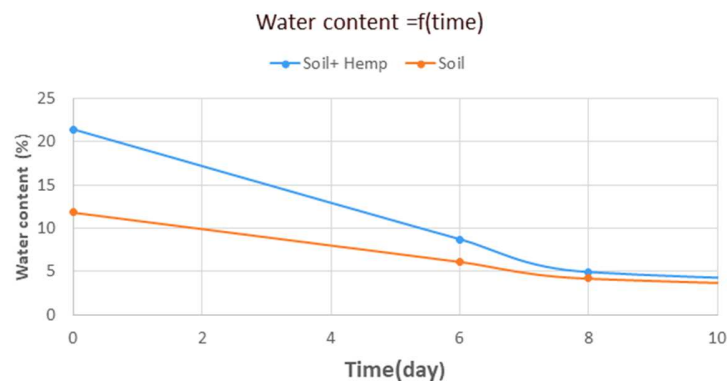


Fig. 6 Monitoring of Drying Process graph

The microstructure was evaluated using Scanning Electron Microscopy (SEM). Fig.8 shows the SEM image of the hemp particles embedded in the soil matrix. The red line corresponds to a vacuum generated between the hemp fiber and the soil, during the soil beating procedure, by means of pressing technology [17]. That determines a mechanical cohesion with the water coming out of the clay contained in its grain volume of circa 10%, while 30-50% is of silt and 40-60% of sand.

The holes observed in figure 7, play an important role in the adhesion between the materials, since these voids will be filled by the binder (the soil in our case), which will trap the air and improve the thermal insulating effect of the materials.

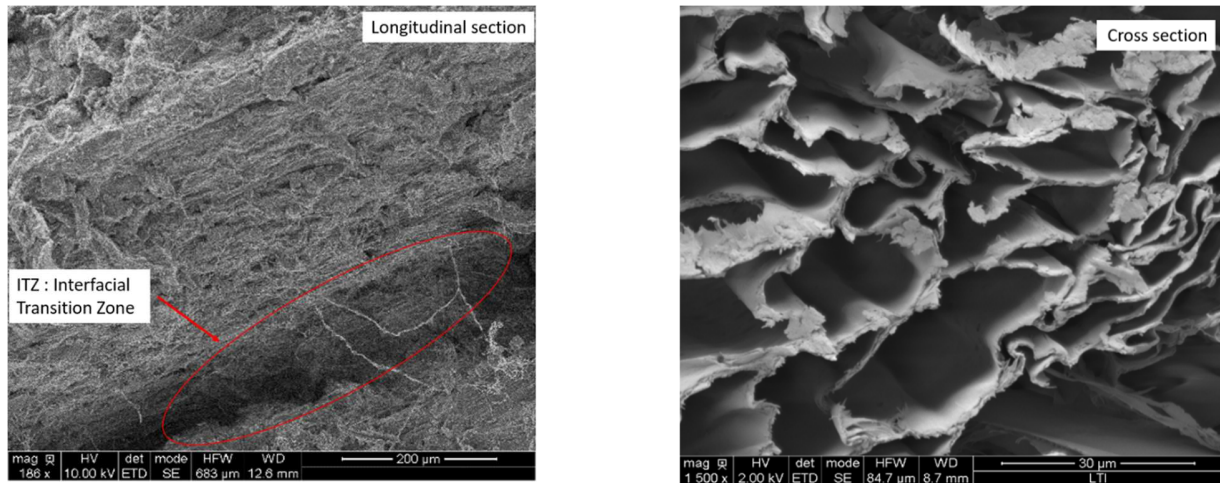


Fig. 7. Images showing particles of hemp embedded in the soil matrix

In the (Table 4) we gathered the chemical composition of rammed earth sample. The analysis shows that the most abundant oxides in the sample are Si, Al and Fe, while K, Mg and Ca are present in small amounts. It also reveals that the soil fractions is rich with silica and alumina, with a slightly significant percentage of iron, while the other elements are present with low quantities.

Table 5. Chemical composition of soil

Element	Wt%	Wt% Sigma
C	31.68	0.88
O	40.77	0.74
Mg	0.67	0.09
Al	6.40	0.19
Si	9.29	0.24
K	1.44	0.17
Ca	1.79	0.20
Fe	7.95	0.97
Total:	100.00	

Capillary absorption is primarily the transport mechanism for water in the tiny pores in construction material, such as rammed earth, due to surface interactions between the water and the pore wall, the circulation of water inside the pores of the material disturbs its fundamental properties, mainly the mechanical and thermal properties. Thus, it leads to a phenomenal reduction of the durability of the material. The capillary water absorption test was conducted at room temperature (19 °C), on samples measured 40 x 40 x 80 mm, already prepared and dried to obtain a constant dry weight. In order to ensure a one-dimensional flow and to avoid any exchange of humidity with the air, a heat-shrinkable plastic film has covered the side faces in terms to be waterproofed. A height of 5 mm had cut on the sides to ensure contact of the test piece with the water. The contact has been conducted indirectly by adding a semi-absorbent layer between the water and the samples, since material dissolves directly in contact with water shown in Fig.8.

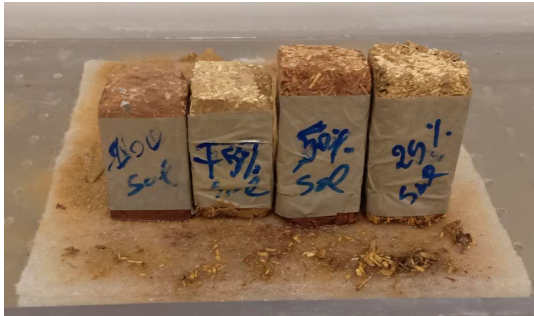


Fig. 8. Capillary water absorption

Table 6: Sorptivity values for different composition

Material	Sorptivity S (cm/mn ^{1/2})
MS1	1.012
MSC75	0.767
MSC50	6.709
MSC25	8.369

The results of capillary water absorption shown in (Table5), present the evolution of sorptivity as function as the amount of fiber inside the rammed earth. This clearly shows that the presence of hemp particles, in rammed earth material, tends to increase the capillary absorption capacity, and to considerably accelerate the kinetics of absorption [18].

The 28-days stress-strain diagram of samples with respect to the hemp particle content is presented in Fig. 9. The results indicated that the increase of hemp particles volume leads to reduction of compressive strength. The value decreases from 1.83 MPa, for the reference specimen MS1 (100% of the soil) to 1.04 MPa for sample containing 25% volume of hemp (MSC75). It corresponds to a reduction of approximately 43%.

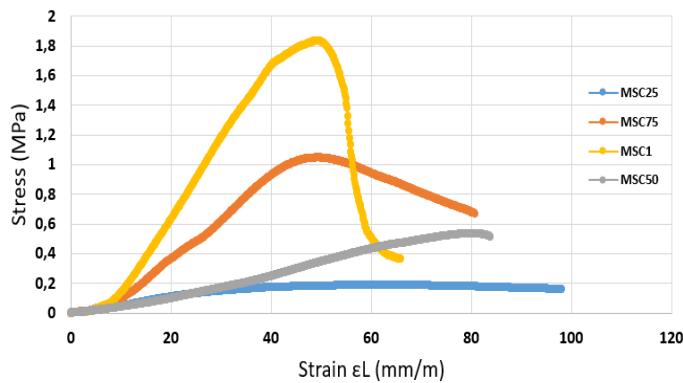


Fig 9. Stress-Strain diagram of samples

Table 7. Parameter-values of compressive-test

Specimen	Compress. Strength (MPa)	Ultimate Strain (mm/m)	Elastic Modulus (MPa)
MS1	1.83	49	52
MSC75	1.04	49.7	29.2
MSC50	0.53	80.3	8.5
MSC25	0.18	56.4	5.1

The decrease in compressive strength is related to the mechanical properties of hemp materials. The low strength of hemp may be the most important limiting factor affecting the mechanical properties of the sample that leads to interfacial bond defects between particles and matrix. The decrease in compressive strength is depended to the porous structure of the sample [19].

The curve of MSC25 shows that the sample has a very large elastic zone, which indicates that the material has the ability to resist distorting influence and return to its original size and shape, unlike the specimen MS1 that has a small elastic phase, indicating the fragility of the material. Noting also that porosity of the material has a major influence on the mechanical properties, in other words the lighter the sample and the lower its mechanical strengths [20].

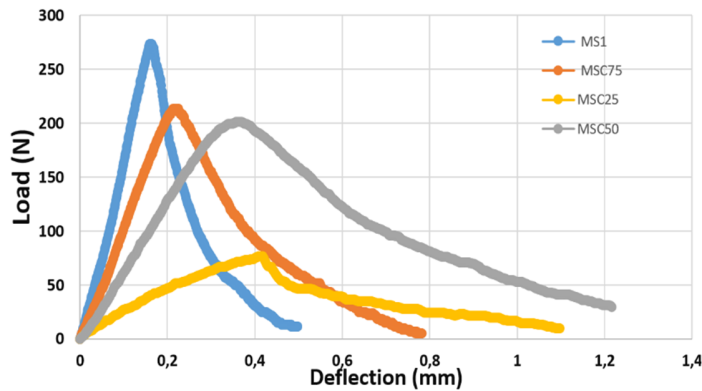


Table 8. Parameter-values of flexural-test

Specimen	Flexural Strength (MPa)	Ultimate deflection (mm)	Elastic Modulus (MPa)
MS1	1.03	0.16	621.2
MSC75	0.80	0.22	443.2
MSC50	0.75	80.3	8.5
MSC25	0.28	0.42	88.8

Fig. 10. Load-Deflection diagram of samples

The 28-days load-deflection curves in flexural behaviour with different hemp volume is shown in Fig. 10. It is based on the results obtained in (Table 7); we observe that the flexural strength decreases as function of adding the hemp particles. The value of flexural strength of the reference specimen MS1 decreased from 1.03 MPa, to 0.28 MPa for MSC25 sample which refer to the formulation of 25% of soil + 75% of Hemp. Furthermore, this reduction of the flexural strength indicates about a percentage of 73% [21].

Conclusion

In this preliminary study, we are interested in studying the effect of hemp particles on traditional rammed earth material, therefore an experimental protocol was conducted in this study to develop and collect data about properties of lightweight rammed earth based on hemp particles. The test results indicated that there is an interesting potential for the use of hemp particles in earthen mixes to produce lightweight construction materials usable in rammed earth applications, such as load-bearing wall materials, and for marked use in tertiary building. The result-tests performed on multiple samples have shown that the material reached a dry unit weight of about 1250 kg/m³ with a compressive strength of 1.83 MPa. In fact, the results of capillary water absorption show that the sorptivity increases with the hemp content and it varies from 1.012 cm/min^{1/2}, for the MS1 sample, to 8.369 (cm/min^{1/2}), for the MSC25 specimen. Then a problem arises with the new formulation of rammed earth, with the presence of water flow inside the material that can damage the microstructure of the material, leading to an increase in convection and conduction of the heat flow, with a consequent decrease of mechanical properties. Moreover, during this research, we studied the mechanical properties based on the amount of hemp particles added to rammed earth. The reduction is related to the addition of hemp particles, which leads to the porous structure of the samples. This innovative scientific experimentation suggests that both mechanical properties of particles and sample's porous structure, reduce the mechanical strengths of the new formulation of rammed earth, proving also that the reduction in flexural strength is lower than that in compressive strength, probably due to the dilution effect of hemp particles.

This research highlighted the effect of hemp particles to attain substantial properties of innovative rammed earth materials. Despite the positive implications of the test results, further research is needed to examine the effect of varying amounts of hemp in each formulation, on the physical-mechanical and thermal properties of the materials to be used for best efficiency with energy savings and sustainability in rammed earth constructions.

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