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Parametric Study on the Implementation Process Effect on Microstructure of Earth Construction

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Abstract

The use of earth as a building material is sustainable and conserves cultural character, reduces energy consumption, is environmentally friendly, and provides a healthy and convenient indoor climate. In this paper, cob like and adobe like specimen were produced in the laboratory and the effects of implementation technique on microstructure of the earth specimen are studied. The soils were characterized by the grain size distribution, Atterberg limits, and MBV tests. The earth specimen was produced with and without fiber after which they were dried at 40 °C and conditioned at 20 °C and 50% RH until a steady mass was obtained. The study of the hydromechanical (suction) and microstructural properties (SSA, pore volume) of fibered and non-fibered cob and adobe like earth specimen were carried out using the WP4C dew point potentiometer and with the micrometrics TriStar II PLUS using BET method respectively. The differences in Manufacturing water content (Wm) and compaction energy in the production of earth specimen during the implementation stage is explored in the changes in the microstructure of the specimen. In the presence of fibers, the suction in cob is high due to the high compaction energy in cob implementation. The specific surface area and size of hysteresis is dependent on the type of soil. The addition of fiber maintains or increases the absorbed quantity of nitrogen depending on the technique and type of soil. There is a high presence of mesopores in cob and adobe specimen.

Keywords

Cob, Adobe, Suction, Microstructure, Pore volume, Specific surface area

Abbreviations

MBV: Methylene blue value; SSA: Specific surface area; LI: Liquidity index; LL: Liquid limit; PL: Plastic limit; PI: Plasticity index; RH: Relative humidity; PSD: Pore size distribution; Sr: Degree of Saturation; BET: Brunauer-Emmett-Teller.

Introduction

The smart use of natural resources is one of the fundaments of sustainable development in any community, according to the United Nations [1]. The building industry affects the three dimensions of sustainability (environment, society, and economy) which are important aspects of long-term development. This industry consumes a vast number of natural resources and, as a result, generates over half of all waste in Europe [2, 3]. Earth construction can be an outlet to decrease the exploitation of non-renewable resources in the construction industry for sustainable development. Earth is a sustainable building material that conserves cultural character, reduces energy consumption, is environmentally friendly, and provides a healthy and convenient indoor climate. It also optimizes operational and maintenance practices and cuts down demolition waste [4-6]. Existing earth building heritage shows the choice of techniques of construction were attributed to factors like soil composition, geography, climate, and the labor force at the site at time of construction [7].

Although earth construction comes with merits afore mentioned, some authors opine there are shortfalls in soil selection, labor cost, duration to complete building and economic wise. There is also the cliché of societal status as people think the poor uses earth for building their houses [8] and see it as a weak material [9] and the posed question of durability in terms of strength and stiffness even though there are existing heritage buildings over centuries old. On the other hand, some authors argue that the earth building techniques are socially inclusive and allow cheap auto-construction due to low material cost [10, 11]. The mechanical and durability performance are affected by intrinsic factors like particle shape, sizes, arrangement of particles, individual composition of particles, and PSD and extrinsic factors like manufacturing water content, compaction energy, temperature, and RH [12].

Kouakou and Morel [13] opine that hydromechanical and microstructure properties like the dry density, unconfined compressive strength, suction, and pore volume of construction materials depend on several factors including the characteristics of raw material and the manufacturing process. Harries et al. [14], posit that the variation in moisture content is the most important influencing parameter to the structural integrity of earth material. The strength, stiffness and durability of earth is controlled by the soil water capillarity generated during inter granular bonding in the soil [9]. The strength and stiffness are important during construction, service life until the end of life of earth buildings and are dependent on suction, water content, density, and PSD.

Therefore, the variation in manufacturing water content influences the structural behavior of the earth material [9]. The various earth construction techniques arise from the differences in quantity of water changes the soil consistency from solid to moist, to plastic, viscous and finally to liquid [14]. The constraints and ways of implementation associated with the different construction techniques used earth construction, limits this study to experimental results for cob and adobe like techniques.

Cob technique involves mixing plastic earth and straw using hands and feet to produce clods that are stacked on each other to build a monolithic wall. The drying time range for cob is between 11 - 21 days depending on the weather. It is classified as a wet method because of the water content of mixture and the densification through the dry-shrinkage process. The earth mixture is implemented directly at manufacture water content in order to build a monolithic wall or by infilling of a wooden structure [15].

Adobe technique consists of earth, water and sometimes straw moulded into a simple brick that is sun-dried. It is a wet method because the manufacturing water content is between the PL and LL. It involves arranging masonry units to form a load-bearing wall, but it is implemented dry, and the bricks gain their strength through the drying process [16]. In unsaturated soils, which is the case with earth buildings, the stiffness and strength increases when suction increases and Sr decreases [9]. The suction effect is controlled by the distribution of pores, smaller pores cause high suction [17, 18]. According to Das et al. [19], the presence of mesopores is said to contribute massively to the strength of the specimen. Therefore, it is essential to study how the implementation process affects the microstructure of earth specimen.

In the present paper, the easiness and workability of a soil and particularly the distribution of voids in the soil because of the manufacturing water content is studied. This current work investigates the influence of implementation process encompassing the manufacturing water content, energy of compaction, and fiber content on the microstructure (SSA and pore volume) and hydromechanical behavior (suction) of cob like and adobe like specimen produced with four-earth collected from earth heritage sites in France.

The literature review on the subject, the gaps found in the literature and the additional research required in answering the gaps are covered in section 1. The materials and methodology carried out to answer the gaps stated in section 1 are presented in section 2. The geotechnical characterization of the soils, the hydromechanical behavior (suction) and the microstructural study (the SSA and pore volume using the BET using Nitrogen to understand the changes in the PSD in earth specimen are presented here. The results and analysis from the thorough experimental campaign is presented in section 3. The discussion from the results and conclusions are found in section 4 and 5, respectively.

Materials and Method

In this paper, a compatible methodology is developed for earth construction with a clearer understanding of the parameters that govern the physicochemical and microstructural parameters of earth in the plastic state. Four on-site materials from heritage sites in France were used in this study. The physical and geotechnical characteristics and geographical location of the soils placed them in specific earth construction techniques (Figure 1). The suitable cob soil was used to produce adobes and vice-versa. The implementation process (compaction energy and manufacturing water content, mixing time) is different for cob and adobe techniques. Earths are nanoscale materials.

Selection of soils and fiber

The soils were randomly selected from regions with history of earth heritage to check the soil compatibility to the various earth construction techniques. Soil B is from Saint-Sulpice-la-forêt in the Brittany Region. The soil is known to be suitable for cob heritage. The material was excavated from the construction site of a public gymnasium belonging to the municipality [20]. Soil C is from an old, demolished adobe house in a town called Pomacle in the Champagne region. Soil O is collected from a construction site in a town called Seilh in the Occitanie region, which has a large adobe heritage. Soil A is collected from a rammed earth building in a

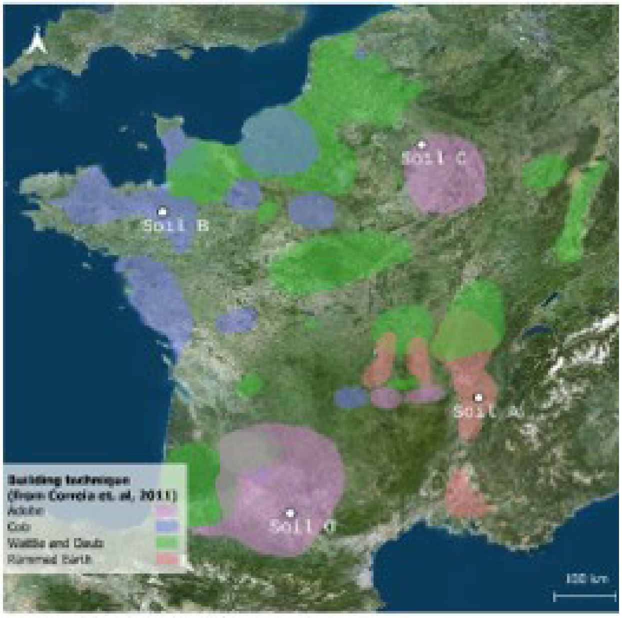

Figure 1: Location of soils used in study on earth heritage map.

town called Nantouin in the Auvergne-Rhône-Alpes region. The soils used in this study are identified using letters. The letters denote the names of regions where they were obtained. B for Brittany, C is for Champagne, O for Occitanie and A is for Auvergne-Rhône-Alpes. The fiber used in this study were from the chopped wheat straw fiber from Britany. The fibers were characterized by randomly picking 100 individual fibers. The length and width of the fibers were measured with a rule to determine the average slenderness ratio of a fiber used in the cob and adobe techniques. The average fiber length is 58 (± 17) mm with an average diameter of 0.45 (± 0.12) mm and an average slenderness ratio of 135 ± 51.

Soil characterization

The geotechnical characterization test carried out are the grain size distribution (ISO 17892-4:2016), Atterberg limits (ISO 17895-12:2018) and the MBV test (NF P 94-068). The geotechnical test performed, the geotechnical properties and the standards followed have been listed in table 1. From the grain size distribution presented, the amount of fines ranges from 73% to 89%. As per NFP 11-300, all soil B, C, and O are classified as fine soils (type A_1m) and soil A is A_1h. Using the Unified soil classification system soil B and A are low plastic silty sand material (SM-ML). Soil C - low plastic silty sand with inorganic clay material (SM-CL). Soil O is a low plastic silty sand with organic clay material (SM-OL).

Table 1: Geotechnical characterisation of soils.

Characteristics	Soil B	Soil C	Soil O	Soil A
Gravel (%)	14.6	13.9	11.0	7.0
Sand (%)	7.2	13.1	4.0	4.0
Silt (%)	46.2	39.0	45.0	56.0
Clay (%)	32.0	34.0	40.0	33.0
LL (%)	44.8	29.9	34.5	28.7
PL (%)	30.8	20.5	21.8	21.2
PI (%)	14.0	9.4	12.7	7.5
Activity of soil	0.44	0.28	0.32	0.23
Dry density (KN/m^3)	17.8	17.5	19.7	18.5
OMC (%)	19.2	17.4	12.0	14.0
MBV (g/100g)	1,17	1,21	2,15	0.54

Specimen production

In the interest of clarity, the term earth in this paper refers to a building material consisting of a mixture (plastic, that is dry side of plastic state or viscous, that is wet side of plastic state) of soil and water with the possibility of fiber addition for reinforcement without any chemical additions. The term fibered and non-fibered cob or adobe indicates cob and adobes with fibers and cob and adobe without fibers respectively. The term cob from this point forward denotes earth mixed with a water content (on the dry side of plastic state) like that of cob on field but production in the lab is quite different from on site. The adobes are produced with water content on the (wet side of PL).

The manufacturing water content of cob found in recent studies showed the manufacturing water content around the PL [20]. The manufacturing water content for cob and adobe techniques was controlled through Atterberg limits test. The LI showing the level of consistency between the PL and LL was used to show the difference in consistency at time of mixing. It was calculated based on the manufacturing water content and Atterberg limits of each soil (Table 2). It is between 0 (PL) and 1 (LL). The increase in water content of the soil increases its LI and firmness decreases. Adobe had higher manufacturing water content giving them a higher LI than cob (Table 2). The water content of production was peculiar to each soil for specimen produced with or without fiber for a technique. The mixture of soil and water with and without fiber were mixed in a mixer for 10 minutes for cob and 12 minutes for adobe because the more water in adobe made it easier to mix but required longer time to evenly distribute the water in the mixture. The mixing water affected the time of mixing and the consistency of the soil. Cob mixture had a plastic feel where adobes had a viscous feel.

The soil mixture was stored in sealed plastic bags for about 24 h to allow moisture content homogenization. After homogenization, a sock was used to layer the mold on the inside. According to [20], a sock placed between the mold and the specimen allow to reduce edge-effect, track shrinkage during drying, and make unmolding easier by preventing the soil from sticking to the sides of the mold when demold to get smooth surfaces (Figure 2). The mold was placed on the flat surface and the plastic soil mixture was put into the molds. The specimen was compacted in eight layers for the case of cob [17]. Compaction of 25 blows per layer was applied with a manual normal proctor compaction device (NF P 94-093) [21-23].

The mixture was hand pressed into the cylindrical molds to form the adobe specimen. The top surface of the specimen was levelled. Cylindrical samples of 150 mm diameter and 300 mm height were produced by cob and adobe technique. This was done to help into the comparison of adobe specimen to cob specimen and avoid shape effects. The mass of the specimen was recorded, and the specimen was put in an oven to dry at a temperature of 40 °C.

Table 2: Manufacturing water content, LI, and nomenclature used in specimen identification.

Soil	Region	Technique	Wm	Liquidity index	Presence of fibers	Nomenclature
Soil B	Brittany	Cob	31	0	No fibers	BCN
					Fibers	BCF
		Adobe	36	0.4	No fibers	BAN
					Fibers	BAF
Soil C	Champagne	Cob	23	0.3	No fibers	CCN
					Fibers	CCF
		Adobe	27	0.7	No fibers	CAN
					Fibers	CAF
Soil O	Occitanie	Cob	21	0.1	No fibers	OCN
					Fibers	OCF
		Adobe	25	0.3	No fibers	OAN
					Fibers	OAF
Soil A	Auvergne-Rhône-Alpes	Cob	22	0.1	No fibers	ACN
					Fibers	ACF
		Adobe	26	0.6	No fibers	AAF
					Fibers	AAN

In the case of fiber addition, the same manufacturing water content was used. The manufacturing water content was determined according to French standard (NF EN ISO 17892-1) with a drying temperature of 107.5 ± 2.5 ˚C. The same protocol used for production of cob and adobe were followed but this time 1% by mass fiber was introduced into the mixture during the mixing stage. The diameter of the mold and the slenderness ratio of the cut straw prompted the selection of the type of fiber chosen.

The drying temperature of sensitive soil must not exceed 50 ˚C according to the French standard NF P 94-050. Ciancio et al. [21] stated that oven drying at higher temperatures may have effects on the suction which in turn affects the mechanical strength. The drying temperature in the oven for the earth specimen was set to 40 ˚C [20]. The specimen was demolded after 7 - 10 days and the weight of the specimen was recorded once a week until a constant mass was achieved, as well as the appearance of surface dryness. The steady state protocol for the drying experiment (duration in oven to conditioner) was the difference between two masses recorded with a minimum of an hour should not be more than 0.1%. The specimen was transferred into a conditioning chamber at 20 ˚C and 50% RH. The specimen was considered steady when the difference between last mass and the precedent mass recorded after 24 h was less than 0.1%. The water content at steady state (Ws) that is, the water content at which the mass was steady was determined. The specimen has a height to diameter ratio of 2:1.

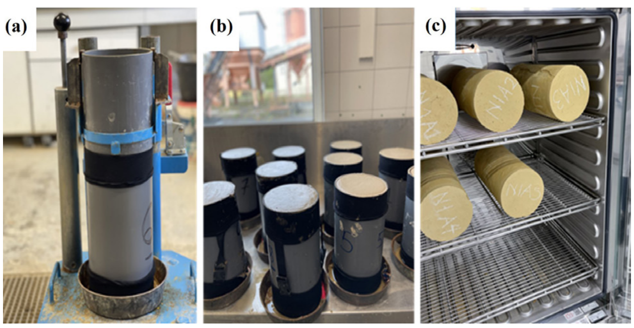

Figure 2: (a) Mold for cob and adobe production, **(b)** freshly produced specimen, and **(c)** specimen in conditioner.

There were 16 batches of production with five replicates for each. In this paper, 70 specimens were studied. The specimen produced in this study are identified using letters and numbers (Table 2). The first letter shows the region of the soil. B for Brittany, C is for Champagne and O for Occitanie region, and A is for Auvergne-Rhône-Alpes region. The second letter shows the technique of production (C for cob and A for adobe), the third letter tells whether it has fiber or no fiber (F for presence of fibers and N for no fibers). For example, ACN1 first replica specimen made from soil from Auvergne-Rhône-Alpes region using cob technique with no fibers. The following nomenclature is used in identifying the specimen. The specimen OCN and OAN had a lot of shrinkage that caused failure and so from this point forward, there is not any data for them.

Hydromechanical and microstructural investigations

A thorough experimental campaign of tests like water content test, suction test, and BET using Nitrogen were conducted on pieces from the cob and adobe specimen to understand the effects of implementation process on the PSD in earth specimen. To prevent changes in moisture content due to air interactions, the dried cob and adobe pieces were placed in a plastic bag and sealed until physicochemical and microstructural analyses were completed.

Soil water content test

Broken specimen pieces are taken to determine the gravimetric soil water content at steady state. The water content in the broken specimen pieces were determined at the time of UCS test according to the standard (NF EN ISO 17892-1) with a drying temperature of 107.5 ± 2.5 ˚C.

Total Suction measurement

The water activity was measured through suction using the WP4C dew point potentiometer (Decagon device) [24]. Small pieces of the broken specimen after UCS test were taken and placed in the sample cup of about 10 g and spread to cover all the base surface area of the sample cup. The sample cup was tapped gently to avoid air trapping and pushed into the drawer to start the suction measurements. After 3.5 min, the first suction value in MPa was displayed on the screen when there was a deep and flashing LED light. The measurement was continued for 30 min, and the average value is found. The measurement is continued for 30 min, and the average value is found.

Microstructure study - SSA and pore structure measurements by BET

The SSA of the specimen was analysed with BET test with the micrometrics TriStar II PLUS [22] [26]. The SSA in soil is measured in the broken pieces of specimen using nitrogen gas [23]. The samples were freeze dried for 48 h and degassed at 50 °C. Nitrogen gas was injected at a temperature of 77 K and at a pressure (p) lower than the equilibrium/saturation gas pressure 5 (p_o). The amount of adsorbed gas is assumed to correspond to the total surface area of the particles. The adsorbed gas is evacuated by the same process, and it is called desorption [25]. By applying the Kelvin equation in equation 1, the samples PSD is determined.

$$r_k = \frac{2.v_{m.\gamma.\cos\theta}}{R.T.In\left(\frac{p}{p_o}\right)} \quad (1)$$

Where, r_k is the radius of curvature for the condensed gas inside the pore, V_m is the molar volume of an ideal gas, γ is the surface tension, θ is the contact angle and R is the gas constant. The procedure above is known as the Barrett-Joyner-Halenda method [26] where the PSD is obtained from the isotherms from BET.

The classification of the microstructure was done according to the International Union of Pure and Applied Chemistry system. In this system, micropores are pores with diameter less than 20 Å. Mesopores are in the range of 20 Å - 500 Å and macropores are pores with diameter above 500 Å.

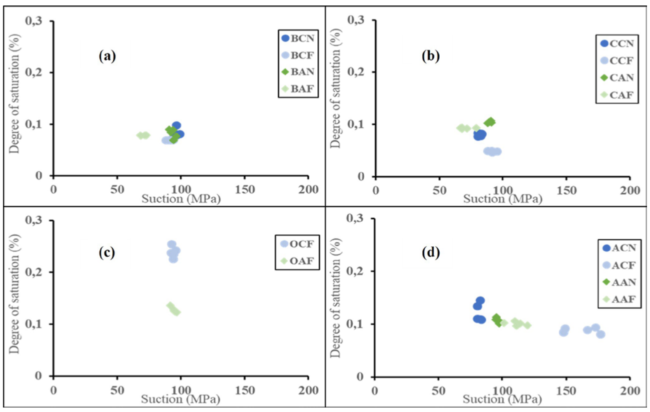

Figure 3: Sr and suction at steady state in all soils for fibered and non-fibered cob and adobe specimen.

Results

Comparative evaluation of suction levels in cob and adobe specimen

The suction levels at steady state in cob and adobe specimen with and without fiber for all soils are presented in figure 3. The suction level is similar for cob (96.2 (± 1.9) MPa, 81.9 (± 1.5) MPa, and 92.1 (± 13) MPa) and for adobe (93.3 (± 2.2) MPa, 89.6 (±1.1) MPa, and 96.5 (±1.3) MPa) without fiber for soil B, C and A, respectively (Figure 3a, 3b, and 3d). The addition of fiber reduces suction for cob (91.5 (± 2.3) MPa, 91.2 (± 2.5) MPa and adobe (70.6 (± 2.2) MPa and 70.6 (±5.1) MPa) for soil B and C. On the other hand, in soil A, fiber addition increases suction in cob (162.7 (± 13.5) MPa and adobe (111.2 (± 6.7) MPa. In the addition of fiber, cob samples have a higher suction than adobes (all soils) (Figure 3). This could be due to the compaction energy present in cob but absent in adobe during implementation and the use of a mechanical mixer helped in the evenly distribution of the fiber in the soil mix. Although in the case of adobes, the high manufacturing water content was supposed to increase the suction through the drying shrinkage [16], the impact of mixing intensity (more water, more time for mixing and more dispersion) impacted the microstructure of adobes affecting the suction.

Moreover, without fiber cob turn to have higher degree of saturation than adobes but the addition of fiber reduces degree of saturation in cobs than in adobe whether adobes have fiber or not [Figure 3a, 3b, 3c, and 3d].

Comparative evaluation of nitrogen adsorption and desorption isotherms and SSA in cob and adobe

The SSA and quantity of nitrogen adsorbed for cob and adobe specimen with or without fiber is presented in figure 4 and figure 5, respectively. The difference in the SSA for cob and adobe is < 2 m^2/g for a soil. The addition of fiber reduces the SSA in all soils by 5.2% for cob and 7.7% for adobe. The quantity of nitrogen adsorbed is dependent on the SSA. The peak of the isotherms shows the total quantity of nitrogen adsorbed by the soil. Soil B has a SSA of 15.6 (± 1.2) m^2/g. The addition of fiber increases the quantity of adsorbed nitrogen from 23 cm^3/g to 28 cm^3/g. The quantity of adsorbed nitrogen gas in adobe without fiber is 31 cm^3/g and decrease by 5

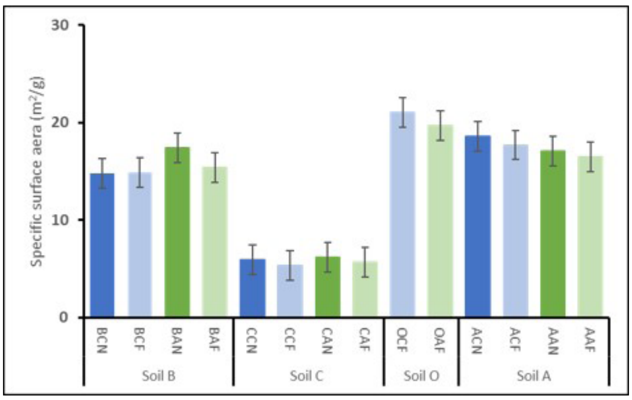

Figure 4: Distribution of average SSA for fibered and non-fibered cob and adobe specimen for all soils.

cm^3/g when fiber is added (Figure 5a). Among the soils, C which is the soil with least fines has the least SSA of 5.7 (± 0.4) m^2/g and least adsorbed nitrogen of 0.5 g/cm^3 (Figure 5b). Soil C do not show any difference in absorbed nitrogen between cob and adobe. With a SSA of 20 (± 1) m^2/g, soil O has a similar trend for the adsorption and desorption of nitrogen in cob and adobe. Same quantity of nitrogen (24 cm^3/g) is absorbed in cob and adobe (Figure 5c). In soil A, the SSA is 17.5 (± 0.9) m^2/g. The isotherms for cob with and without fibers are similar, meaning even with the presence of fibers, similar quantity of nitrogen 28 cm^3/g is absorbed. In adobes, the addition of fiber increases the adsorbed nitrogen by 50% (from 14 cm^3/g to 27 cm^3/g) (Figure 5d). This could be due to the implementation process, but interestingly, the addition of fibers reduces this difference.

Therefore, the addition of fiber maintains or increases the absorbed quantity of nitrogen depending on the technique and type of soil. Also, the type of soil determines the SSA, but the adsorbed quantity may depend on the technique of implementation. The distinctive hysteresis seen for the adsorption and desorption of nitrogen due to the delay in capillary condensation and evaporation (Figure 5a, 5c, and 5d) that occurs in mesopores [26-28].

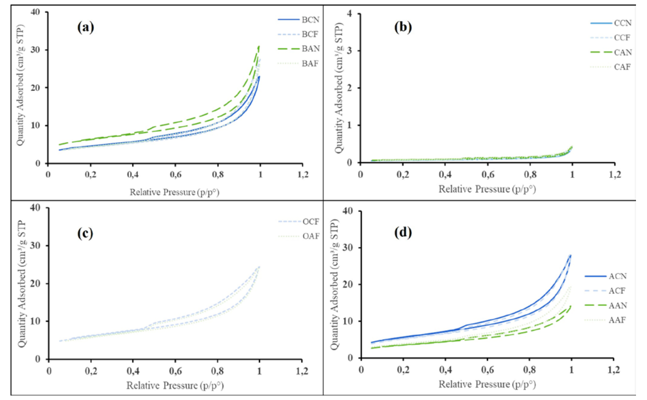

Figure 5: Evolution of nitrogen adsorption and desorption isotherms in fibered and non-fibered cob (blue) and adobe (green) for all soils.

Evolution of microstructure in fibered and non-fibered cob and adobe

The pore structure using BET method in cob and adobe with and without fiber is shown in figure 6. There is similar family of pores but with different intensity for each soil. In figure 6a, there is a sharp increase in pores at 42 Å with the highest volume of pore of 0.056 cm^3/g recorded. The pores are present from 40 Å to 2240 Å. There is a high intensity of pores from 500 Å to 2070 Å. Adobes without fibers have higher pore volume. In the case of soil C, the highest volume of pore of 0.027cm^3/g is recorded at 42 Å. From 65 Å there is not a significant increase in the intensity of pores until 3000 Å. The pores are present from 40 Å to 3000 Å. Fiber addition does not affect the pore volumes of both cob and adobe (Figure 6b). For specimen produced with soil O, the largest pore volume (0.076 cm^3/g) occurs at 46 Å. From 55 Å there is an increase in pore volume until 135 Å after which the pores drop until 1900 Å (Figure 6c). When it comes to soil A, the largest pore volume (0.062 cm^3/g) occurs at 41.5 Å. There is an increase in pores from 500 Å and decrease after 500 Å. The presence of fibers does not cause any variation in pore volume (Figure 6d). The volume of pores in cob is higher than in adobes even when fibers are added to adobes. The pores are present from 20 Å to 1700 Å. Cob and adobe specimen for all soils show the presence of mesopores compared to macropores. This attests to that the delay in capillary condensation and evaporation shows presence of mesopores [26-28].

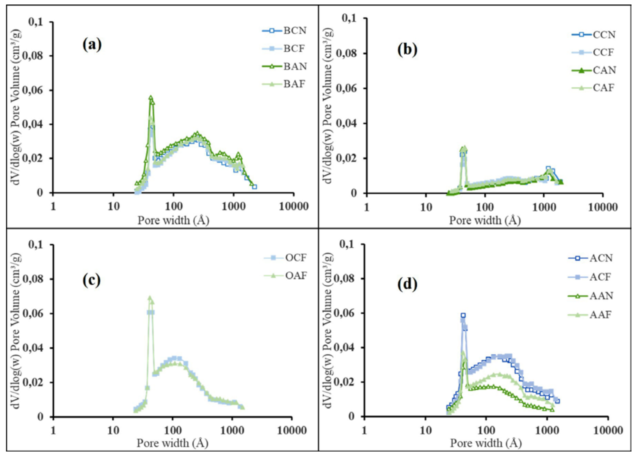

Figure 6: Changes in pore volume and pore width of cob (green) and adobe (blue) for soil B.

Discussion

The observed changes in hydromechanical (suction) and microstructure (SSA, absorption and desorption of nitrogen and pore volume) due to the differences in implementation technique and implementation process parameters like the manufacturing water content, compaction energy and the mixing time for all soils are discussed.

The effects of implementation on microstructure precepts that the manufacturing water content, the time for mixing, the compaction energy and the water content at steady state affect the hydromechanical and microstructure parameters of earth specimen. Although, the entire specimen was conditioned in the same temperature and RH conditions, there is a difference in the suction per the type of soil and type of technique. This could be from the influence of manufacturing factors at the time of implementation. Fiber addition reduces suction in adobes from 93.3 (± 2.2) MPa, 89.6 (± 1.1) MPa to 70.6 (± 2.2) MPa and 70.6 (± 5.1) MPa for soil B and C, respectively, but there is an increase in suction in adobes for soil A from 96.5 (±1.3) MPa to 111.2 (± 6.7) MPa. Also, fiber addition reduces Sr in cob (Figure 3).

The SSA of a soil seems to be an intrinsic parameter and it is more dependent on the composition of soil than the type of technique. Each soil seems to have an intrinsic range of pores associated to it (Figure 4). The type of soil therefore determines the SSA. However, the SSA of adobe turns to increase by at most 2 m2/g. This could be linked to the manufacturing water content [14]. Because more water is used in mixing the soil for adobe, it takes more time to evenly distribute the water in the soil. The soil gets softer and the likelihood of interfering with the pores in the soil is increased. Despite the fact that the SSA of the fibers only is not known to be compared to the soil's surface area, the effects of fibers show a major impact on the macro porosity range (Figure 5 and figure 6).

Moreover, there is a decrease in the SSA in cob and adobe with fiber; this suggests that the fibers when mixed well may favor the packing and arrangement of aggregates of soil reducing the pores but with a lesser intensity (Figure 4). This is probably due to the different ways of fibers embedment in the soil matrix during the compaction phase. The addition of fiber affects the absorbed quantity of nitrogen in adobe than cob (Figure 5).

In addition, the quantity of adsorbed nitrogen may be dependent on the SSA of the soil and the technique of implementation (Figure 5). The fiber causes the quantity of adsorbed nitrogen for a soil to be similar in the case of cob but may increase in adobe (Figure 5). This could be as a result of the high manufacturing water content causing larger pores from shrinkage.

Furthermore, all soils used in this study regardless of the technique of implementation shows a high presence of mesopores compared to macropores. The mesopores have higher intensity around 500 Å (Figure 6a, 6c, and 6d). There is a multimodal distribution of pore for both cob and adobe in (Figure 6a and 6d) whilst for soil O and C, there is a bimodal distribution of the pores (Figure 6b and 6c). The delay in capillary condensation and evaporation shows presence of mesopores [27-29].

Conclusions

The implementation process effect on hydromechanical and microstructure of cob and adobe were studied using fours soils from four regions of France. The geotechnical properties of the soil were determined. Cob and adobe specimens were produced and the hydromechanical behavior and microstructural evolution were experimentally studied. The results from the experiments were used to understand the implementation process effect on microstructure and suction. The following findings have been derived from the study.

- Fiber addition may increase or reduce suction in cob and adobe depending on the type of soil. In soil B and C, the suction in cob reduced from 96.2 (± 1.9) MPa, to 91.5 (± 2.3) MP and 93.3 (± 2.2) MPa, to 70.6 (± 2.2) MPa in adobe. On the other hand, suction increases in soil A from 92.1 (± 13) MPa to 162.7 (± 13.5) MPa for cob specimen and from 96.5 (±1.3) MPa to 111.2 (± 6.7) for adobe specimen.
- The effect of the high manufacturing water content but absence of compaction energy in adobes during the implementation process reduces suction adobe.
- Concerning the soils used in this campaign, the type of soil determines the SSA. However, the SSA of adobe turns to increase by at most 2 m^2/g.
- The quantity of adsorbed nitrogen (28 cm^3/g, 0.5 cm^3/g, 24 cm^3/g, and 24 cm^3/g) may be dependent on the SSA (15.6 m^2/g, 5.7 m^2/g, 20 m^2/g, and 17.5 m^2/g) of the soil for soil B, C, O, and A, respectively, as well as the technique of implementation.
- The addition of fiber maintains or increases the absorbed quantity of nitrogen depending on the technique and type of soil.
- All soils used in this study regardless of the techniques of implementation shows a high presence of mesopores (20 Å - 3000 Å) compared to macropores.
- For further investigations, the mixing step should be as long as possible, to improve the quality of mixing on the sample's parameters like suction.

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Conflict of Interest

None.

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