



## The Porosity of Stabilized Earth Blocks with the Addition Plant Fibers of the Date Palm

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### Abstract

This work is an experimental study to analyze the physical behavior of Stabilized Earth Block (SEB) and reinforced with Plant Fibers of the Date Palm (PFDP). This is part of the valorization of local building materials (earth, fiber) and contributes to reduce the price of housing. Initially, physical tests (Density, Total Water Absorption, and Capillary Absorption) were carried out in preparation for the porosity study. However, the main objective of this study is the investigation of porosity phenomenon using several methods as well as the total porosity estimation, the total volume porosity in water and Open porosity methods, where the mechanical resistance is also considered. In order to improve the stabilized earth block porosity analyses, various dosages are proposed for cement, lime and fiber. Thus (0%, 5%, 10%) of cement, (0%, 5%, 10%) of lime and the combination (5% cement + 5% lime) with (0%, 0.25%, and 0.5%) of fibers for each composition. The experimental results showed that the addition of fibers increases the porosity of the stabilized earth block proportionally and an increasing quantity of the stabilizer reduces the porosity of the SEB, cement is also more effective at closing pores than lime. Moreover, the compositions 10% cement and the mixture of 5% cement + 5% lime with 0% fiber showed a good results of porosity, for this reason they can be used as a durable building material and good resistance to natural and chemical aggression.

*Keywords:* SEB; Plant Fibers of the Date Palm; Stabilizer; Porosity; Mechanical Strength.

### 1. Introduction

Over the past century there has been an important increase in the use of earth as a building material due to its local availability, low cost and ease of its workforce, which makes the earth over time one of the most important building materials in the world. However, the statistics indicate that about 30% of the world population or more lives in earth constructions essentially in desert and arid areas [1]. Today, there is a strong demand for housing where several construction projects of equipment and habitation are launched. Therefore, the use of concrete material becomes more and more expensive and results harmful consequences to the environment by about 25% of their production as global warming and air pollution [2, 3]. Many scientists suggested that the use of local materials, especially earth is the solution to these problems. Nonetheless, it's our duty to proceed with the valorization of earth, taking in consideration that the use of earth as a construction material requires adequate treatment.

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Although, the stabilization technique is one of the oldest techniques adopted for the Adobe manufacture, in which the cement is the most used; improving volume stability, resistance, and durability [4-6], for cement works well, it takes at least 3 to 4% of the weight of the earth, mostly for the sandy earth [7]. These quantities can even reach 10%, but exceeding the 10% the resistance was negatively affected [5, 7, 8]. In contrast, lime is also considered as one of the widely used stabilizer, especially in clay earth, which contains a large quantity of clay [7, 9], by an estimated addition between 4 and 12% [4, 5].

Therefore, the experimental behavior studies of earth and construction materials as well as the porosity and permeability have great importance as indicators of durability. Although, these indicators determined the material's degree of protection against agent penetrations [10]. According to the literature, the definition of porosity is the fraction of total volume occupied by voids. The porosity can be presented in two forms depending on its location to the outside environment: open porosity and closed porosity. The closed porosity had a direct influence on the mechanical and physical behavior of the materials, while the open porosity affected the material surface area [11].

Experimentally, the porosity can be defined by direct methods (Microscopy) or by indirect methods (based on natural absorption, Nitrogen adsorption/desorption, Mercury intrusion porosimetry (MIP), while the water absorption technique is the simplest [12].

The porosity value is an increase in average pore diameter, according to IUPAC the pores ranged in three classes; micro-pores (0.1-2 nm), meso-pores (2-50 nm) and macro-pores (50 nm-10 mm) [12, 13]. According to Mindess [13] another type of pores rest, which is the empty pores > 10 mm, which are created as a result of the inclusion of occluded air at the mixing.

The addition of fibers in the concrete composition is one of the techniques for strengthening the microstructure and limiting the crack network propagation in the concrete matrix. Although, the earth block can be also reinforced using fibers to increase certain intrinsic mechanical performance of the stabilized earth concrete.

Several studies considered the porosity of the SEB, in which the porosity of stabilized earth block composed by earth and recycled aggregates is estimated by 34.7% and 29.9% respectively for unstabilized earth block and stabilized one using 8% of cement [5]. Namango [14] also added sisal fibers (0-0.75%) where the porosity of the block decreased from 33% to 28%. Kerali [15] added cement from 3% to 11% and the porosity decreased from 26% to 14%, he also explained that compaction had a greater impact than a W/Binder ratio. Additionally, the main purpose of this work is the introduction of experimental program including the study of materials properties used and the explanations of the experimental methods. The second stage contains the presentation and discussion of results based on the physical behavior of the earth brick which has been investigated in the preparation of the porosity study by different ways. Hence, a comparative study was conducted on the porosity results, a conclusion and further recommendations were provided.

The porosity phenomenon of the SEB was investigated in this study. The earth block was stabilized using cement and lime with different dosages. Then, the two stabilizers were mixed and used in equal dosages. Furthermore, the influence of the addition of the date palm plant fibers on the behavior of the stabilized earth block was also investigated while the optimal dosage was determined in the previous section of this study.

## 2. Experimental Program

### 2.1. Materials

#### Earth

The earth material used in this study is extracted from (Moughel Ksar located 50Km from Bechar the South West gate of Algeria), earth is the essential material in the manufacture of Adobe used in the Ksar construction; the results of the identification tests are summarized in Table 1.

**Table 1. The physical and chemical properties of the used earth**

Physical properties		Chemical properties	
Parameter's	value	components	%
Absolute density (g/cm <sup>3</sup> )	2.7	carbonates (CO <sub>3</sub> <sup>2-</sup> )	6.8
Apparent density (g/cm <sup>3</sup> )	1.3	sulfates (SO <sub>4</sub> <sup>2-</sup> )	Traces
Sand equivalent ES (%)	11.58	chlorides (CL)	0.39
Liquidity limit (%)	19.45	insoluble (SiO <sub>2</sub> ,MGO,CAO,AL <sub>2</sub> O <sub>3</sub> + Fe <sub>2</sub> O <sub>3</sub> )	92.81
Limit of plasticity (%)	11.36		
Consistency index (%)	0.92	VBS	1.2
Plasticity index (%)	8.09	Activity coefficient Ca	0.87

According to the norm NF P18 560, after putting the earth in the oven (105 °C) during 24 hours, the earth granular distribution is presented in Figure 1. Following the path of grain size graphs, we noted that the granular distribution of this earth converges of the ideal curve. Where, the earth graph situated between the two limits given by the CRATERre [16]. However, the tested earth can be used in the SEB preparation because 70% of the representative graph points situated in the inside the authorized zone.

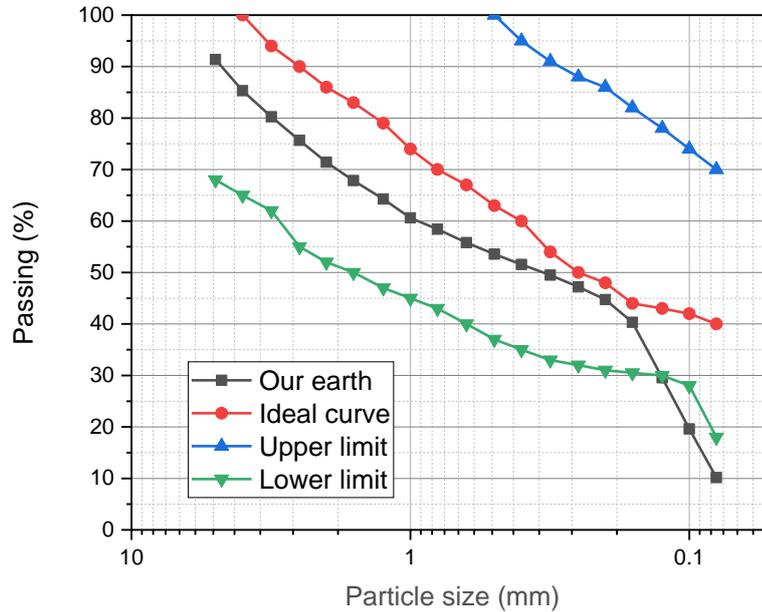


Figure 1. Particle size of the tested earth

The preliminary results identification analysis of the earth given the fineness earth module (Mf) in order of 2.24, noting that the better granular quality module is (2.2 <Mf <2.8) not too fine and not much coarser. According to the Proctor test (NF P 94-093) the optimum water content is  $W_{opt} = 12\%$ , which translates an optimum dry density Proctor  $\gamma_h = 2$ . The Atterberg’s limits were made in accordance with the norm NF P 94-051 and the results are shown in Table 1. Therefore, this earth can be classified as a clay little plastic. On the other hand, the chemical results indicated that the earth doesn’t contain harmful substances, which subsequently favored its use in construction (Table 1).

**Cement:** White cement Type: [CPJ - CEM II / A-L 52.5N NA 442]

It is a white cement with high resistance, from the grinding of a white Clinker, in accordance with Algerian norm (NA 442) and European norm (ENCE 197-1), used for the earth stabilization (Table 2). The reason for what the ordinary cement is not used is that the gray color caused a disfiguration in the site landscape to preserve the basic ochre color of the built heritage (the Ksour of southern Algeria). The physical and chemical properties of the cement are shown in Table 2.

Table 2. The physical and chemical properties of cement and the lime used

Physical analysis	Cement	Lime
Normal consistency	28±3.0	69.5
Finesse following Blaine's method (cm <sup>2</sup> /g) (NA231)	4300 - 5200	11663
shrinkage at 28 days (µm/m)	<1000	/
Expansion (mm)	≤ 3.0	/
Initial setting time (min)	160 ± 40	80
Final setting time (min)	250 ± 40	/
Specific density (g/cm <sup>3</sup> )	3.1	2.24
Apparent density (g/cm <sup>3</sup> )	1.14	0.72
Chemical analysis	Cement	Lime
Fire loss (%) (NA5042)	6.0 ±2	/
Sulfate content (SO <sub>3</sub> ) (%)	2.5±0.5	<0.5
Magnesium oxide content (Mgo) (%)	1.7±0.5	<0.5
Chloride content (%) (NA5042)	0.02 –0.09	/

**Artificial lime**

The hydrated lime used is made by BMSD Company, North-West of Algeria, where the physical and chemical properties are shown in Table 2.

**Vegetable fiber**

The date palm plant fibers were divided into pieces of 20 mm of lengths and 3 mm of width (Table 3) then they are subjected to a physical treatment called the water immersion treatment (Figure 2) for 24 hours. The purpose of this treatment is to reduce the chemical compounds quantity in the fibers (lignin and hemicellulose) to avoid the chemical interactions in the matrix.



**Figure 2. Vegetable fibers of the date palm**

**Table 3. The physical and chemical properties of fiber [17]**

Physical properties		Chemical characterization	Value
Length (mm)	20	Cellulose (%)	32-35.8
Width (mm)	3	Hemicellulose (%)	24.4-28.1
Thickness (mm)	0.55	Lignin (%)	26.7-28
Water content (%)	53.6	Fats (%)	7
Density (kg/m <sup>3</sup> )	720	Absorption coefficient %	132

**2.2. Testing Method and Mix Proportions**

The adopted compositions of white cement and lime as stabilizers are 5% and 10% for each of the gross quantity of earth, and a mixture of 5% of white cement and 5% of lime to make the combination, and a 0% of stabilizer control (only earth), 3 fiber ratios (0%, 0.25%, 0.5%) was added for all previous compositions (Table 4).

**Table 4. Details of Mixture proportions**

Designation	E	5%C	10%C	5%C+5%L	5%L	10%L
Earth %	100	100	100	100	100	100
Cement %	0	5	10	5	0	0
Lime %	0	0	0	5	5	10
	0	0	0	0	0	0
Fibers %	0.25	0.25	0.25	0.25	0.25	0.25
	0.5	0.5	0.5	0.5	0.5	0.5
Water %	30	30	30	30	30	30

(%) is added in relation to the gross quantity of earth.

The quantities of each material (earth- white cement- lime- water- fiber) were prepared and 30% water was added in relation to the earth quantity and the mixture was mixed in 5 liters of kneader. A layer of oil spread on the inside walls of the moulds to facilitate the demolding operation. The compaction of the plain moulds was insured for 30 seconds on a vibrating table and the demolding of the specimens was carried out over 48 hours. Finally, the dried samples were kept in an atmosphere of ( $T^{\circ} = 21 \pm 2C$ , and  $HR = 35 \pm 5\%$ ) for 28 days.

### 2.3. Test Protocol

#### 2.3.1. Incorporated Air Content Test

This test was carried out according to the norm EN 1015-7 in order to calculate the percentage of air inside the mixture (Figure 5).

#### 2.3.2. (Compressive /Flexion) Strength Test

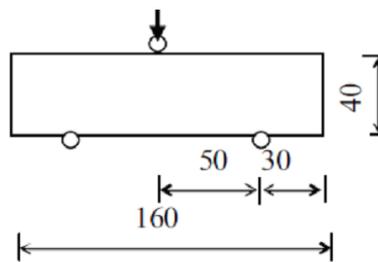
The mechanical tests are carried out according to the standards of mortar cement (NF EN 196-1) on prismatic specimens of  $40 \times 40 \times 160 \text{ mm}^3$ . In order to determine the flexural strength, we used the concentrated load method at mid-range (three-point flexion) with a standard flexural device (Figure 3) and a load speed of 1.14 mm/min. The flexural strength (in MPa) is calculated by the following law:

$$F_s = \frac{1.5 \times F_f \times L}{b^3} \quad (1)$$

$b$ : is the side of the square section of the prism;

$F_f$ : The force applied in the middle of the prism;

$L$ : is the distance between the supports.



All dimensions are in millimeters (mm)



Figure 3. The flexural strength test

The half-prisms obtained after the flexural test were used in the compression test on the side faces of molding section  $40 \times 40 \text{ mm}^2$ . The compressive strength was calculated using the following law:

$$\sigma_c = \frac{F}{S} \quad (2)$$

#### 2.3.3. Density Test

After the 28 days of maturity of the blocks  $50 \times 100 \times 100 \text{ mm}^3$  and put them in the oven ( $105^{\circ}C$ ) for 24 hours the mass was taken from a scale of precision 0.1g and the volume is measured by a calliper.

### 2.3.4. Total Water Absorption (TWA) Test

The test is performed according to the norm (BS 3921 1985) where the total water absorption depends on the water block immersion and measure the extent of his weight gain for 24 hours, using the following equation:

$$TWA(\%) = \left( \frac{M_w - M_d}{M_d} \right) \quad (3)$$

$M_d$ : The weight of dry blocks

$M_w$ : The weight of wet blocks

### 2.3.5. Capillary Absorption Test

The capillary absorption experiment is applied in accordance with the NF P10-502 norm generally used for terracotta and limestone materials. In this experiment, moulds with dimensions of  $50 \times 100 \times 100 \text{ mm}^3$  are used where the blocks are put in contact with water (Depth 1 cm in water) and the quantity of water absorbed is deduced by a simple calculation. The side walls of the block are sealed using plastic insulating paper, forcing the water to take a vertical direction and eliminating the evaporation on the lateral sides (Figure 11). The quantity of water absorbed is determined by the series weighing of the samples at (1/4, 1/2, 1, 2, 4 and 8 hours), the water absorption results are presented by two factors as follows:

$\Delta m(t)/S$ : The quantity of water absorbed in the surface unit.

$Z(t)$ : The height of the capillary imbibing forehead.

### 2.3.6. Ultra-Sound-Test

The ultrasonic pulse velocity is indicated by the direct method where is used a digital sonic auscultation device with 2 transducers of 49.5mm diameter and a frequency of 54 KHZ. The interface of the two transducers is glued to the surface of the block and the run length is 100mm, while these results are taken before the capillary absorption test.

## 3. Porosity

In this study the porosity is calculated by various methods, including:

### 3.1. The Total Porosity Estimation

The total porosity can be calculated through the difference between the theoretical density (real) and the experimental density of the SEB. Where, the theoretical density is the pure density of the particles without voids and without air pores (measured by the pycnometer method) and the total porosity estimation is calculated by:

$$n(\%) = \left( 1 - \left( \frac{\rho_{\text{experimental}}}{\rho_{\text{theoretical}}} \right) \right) \times 100 \quad (4)$$

### 3.2. The Total Volume Porosity In Water

According to Kerali [15], the total porosity can be calculated in the water of SEB by measuring the block weight after water saturation from the initial dry weight, because of the absorbed water by the block which penetrates into accessible pores in the block, the volume of water absorbed to saturation is equal to the total volume of the block pores. Thus, the total water absorption can be converted to porosity using the following:

$$n(\%) = \frac{TWA \times \rho}{100 \times \rho_w} \quad (5)$$

$n(\%)$  = total volume porosity.

$P$  = bloc dry density ( $\text{kg/m}^3$ ).

$P_w$  = water density 1000 ( $\text{kg/m}^3$ ).

$TWA$  = total water absorption (%).

### 3.3. Open Porosity

The open porosity is the ratio between the total voids volume  $V_v$  to the total blocks volume  $V_T$  during (half-hours) as shown in the following equation:

$$n(\%) = \left( \frac{V_v}{V_t} \right) \times 100\% = \left( \frac{\Delta m / \rho}{S \times Z} \right) \times 100\% = \left( \frac{\Delta m / S}{\rho \times Z} \right) \times 100\% \quad (6)$$

Where:

$\Delta m/S$ : The quantity of water absorbed in the surface unit ( $kg.m^{-2}.h^{-1/2}$ ).

$\rho$ : the water density ( $1000 Kg / m^3$ ).

Z: the front capillary imbibition elevation in (m).

A summary of the research methodology are shown in the following chart.

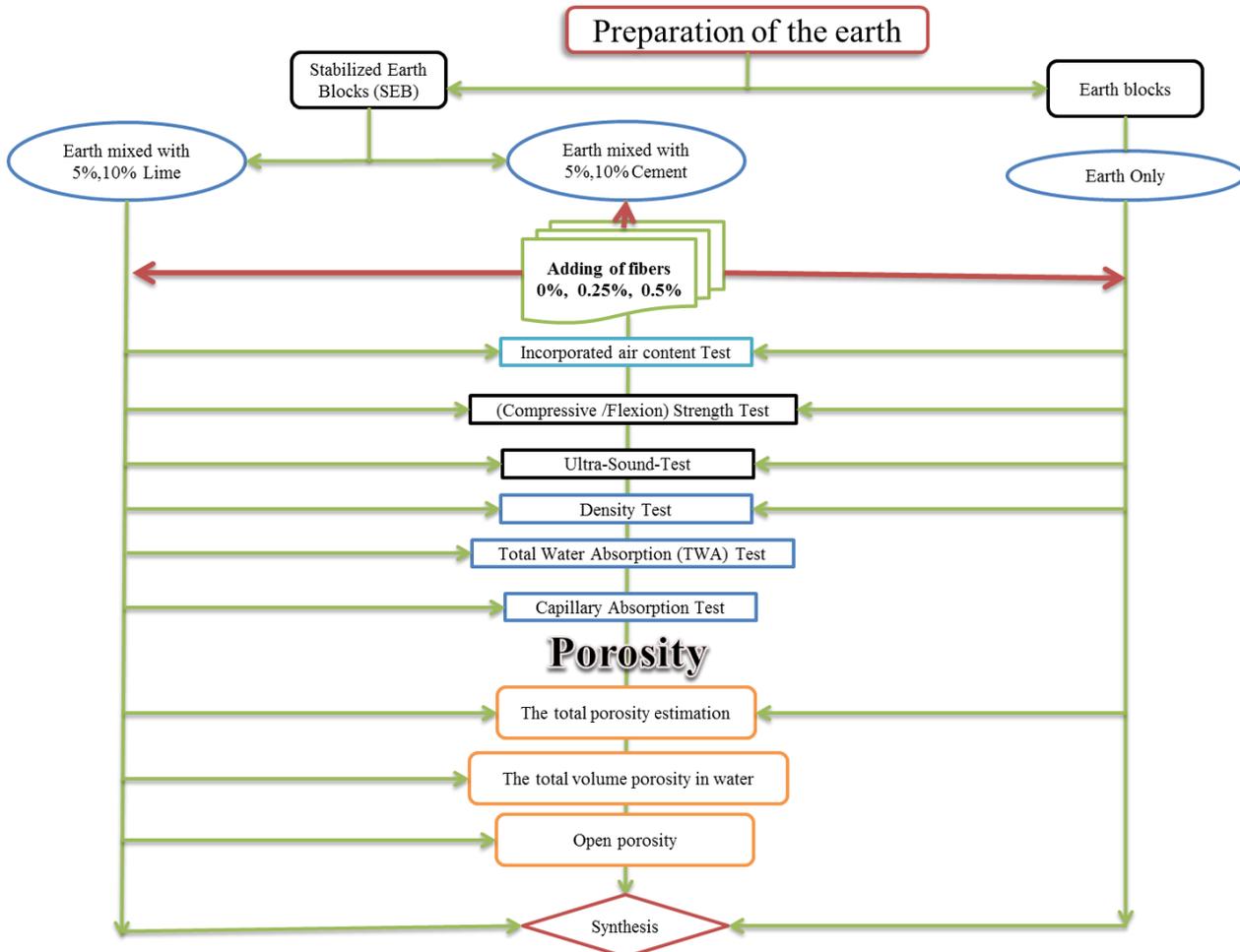


Figure 4. Flowchart of methodological research

## 4. Results and Discussion

### 4.1. Incorporated Air Content

The primary porosity is formed during the paste production in which the voids (quasi-spherical) formed from the trapped air, i.e. trapped air during the mixing (Figure 5).



Figure 5. Incorporated air content Test

Figure 6 shown the incorporated air content in the mixture in the fresh state where it is noticed that the incorporated air increases with the increase of the quantity of stabilizer and fibers. These results can be explained by the change of the internal structure of the mixture. The increase fibers quantity in the matrix has led to an increase in the void volume.

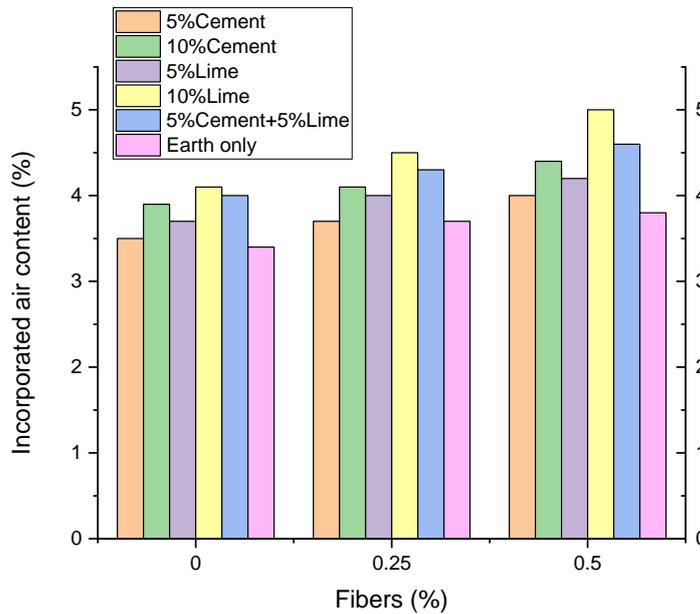


Figure 6. Air content of all compositions

The increase quantity of fiber leads to increase the possibility of collision between the fibers during the mixing operation which means more air. The fibers can also be an obstacle to rising air bubbles on the concrete surface during mixing.

#### 4.2. Compressive and Flexural Strength

The durability of SEB improves with the resistance increasing. However, the compressive strength is considered as an indicator of the masonry hardness, structural elements. Otherwise, the compression of this category of structure is high when the porosity of their materials is low [18, 19].

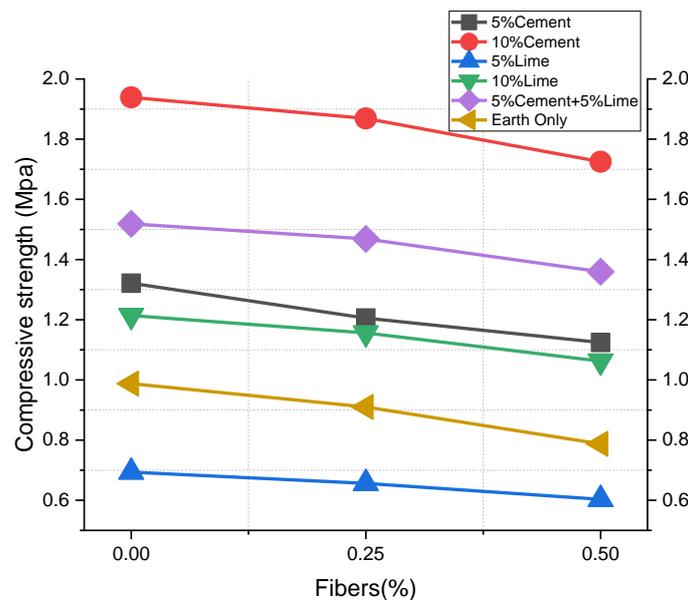


Figure 7. The compressive strength of the SEB at 28 days

The effect of changing the quantity of fiber on compressive strength for SEB at 28 days is shown in Figure 7. The value of 1.93 MPa in compression is the highest value which corresponds to the cement dosage of 10% with 0% fiber. While, the lowest value of 0.61 MPa is that corresponding to a lime dosage of 5% with 0.5% fiber. Note that the

variation of the compression value is proportional to the used stabilizer quantity, because of the reduction of the W/Binder ratio, which means more  $C_3S_2H_3$  and CSH leading to the microstructural stiffness improvement by the formation of numerous bonds between the particles [20].

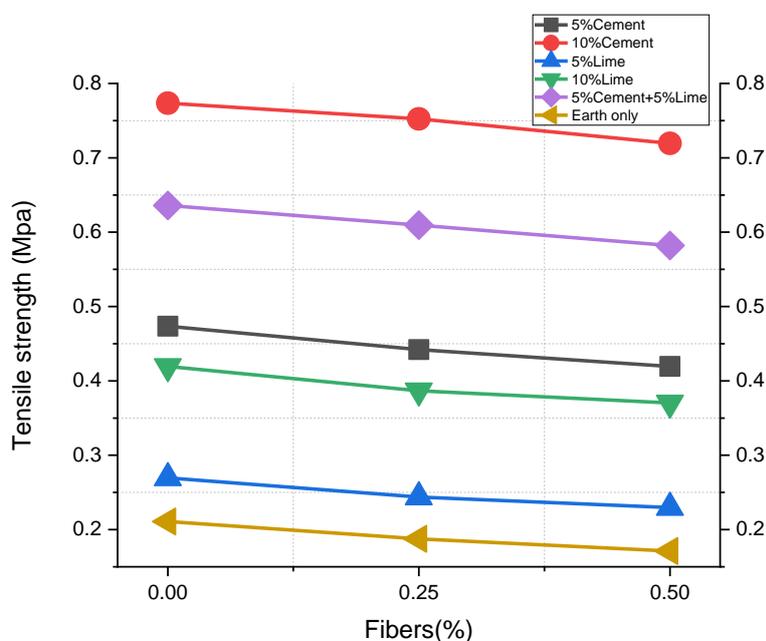
The mixed composition of 5% cement with 5% lime gives a very interesting compression result compared to the 10% lime dosage. Also, the composition of earth without stabilizer gives resistance values closer to the 5% lime dosage resistance. These results can be explained by the fact that lime requires more time and a higher temperature to give a good pozzolanic interaction [21].

On the other side, the fiber quantity increasing caused a marked decreasing compression values for all compositions. Thereby, the highest percentage part of resistance is recorded in the non-stabilized composition (earth only) estimated by 20.29%, where the lowest percentage part of resistance is recorded in the mixed composition of 5% cement and 5% lime. This decrease can be explained by the quantity of chemical reaction products of the stabilizers being small compared to the void quantities resulting from the presence of fibers [22].

This interpretation can be reinforced by the results of the air content test, the air quantity in the mixture decreased proportionally when quantity of fibers decreasing.

Therefore, the compositions of 10% cement and the mixture of 5% of each cement and lime are considered in the compression values recommended by [23].

Natural fibers are introduced into the composition of Adobe and various earth compounds of SEB in the perspective of reducing the phenomenon of shrinkage, cracks development and also the improvement of the bending resistance [24].



**Figure 8. The flexural strength of the SEB at 28 days**

The effect of changing the fiber quantity on the flexural strength of SEB at 28 days is clearly shown in Figure 8. The highest value of the resistance is 0.77 MPa due to the quantity 10% cement and 0% fiber, contrarily the lowest value of resistance is 0.171 MPa attributed to the non-stabilized earth composition. The resistance value varied in proportion to the quantity of stabilizer percentage. Contrariwise, the resistance value varied inversely proportional to quantity of fibers added. Moreover, the highest percentage value of resistance pert is founded on the non-stabilized block estimated by 18%. In contrast, the lowest percentage value of resistance pert estimated by 2.67% is founded in the composition of 10% cement with 0.25% fiber.

According to Minke [25], when a quantity of fibers is added it can isolate the material responsibly of the bond (stabilizer, clay). From there, the points of contact between the fiber and the matrix are reduced. These points are responsible for the transmission of the stress, which means a low charge transfer at the fiber/matrix level, so decreasing the block resistances. This decrease can also be explained by a low matrix/fiber adhesion, since that the surface of the palm leaves is smooth it can also be explained by the non-optimal dimensions or the non-optimal distribution of the fibers in the mould (homogeneity). These results are in agreement with Bouhicha [26], and Piattoni [27].

### 4.3. Block Dry Density

The results of the density variation function of the introduced fiber quantity into the mixture appeared in Figure 9, the figure shown that the density values being limited between 1450 and 1146 kg /m<sup>3</sup>.

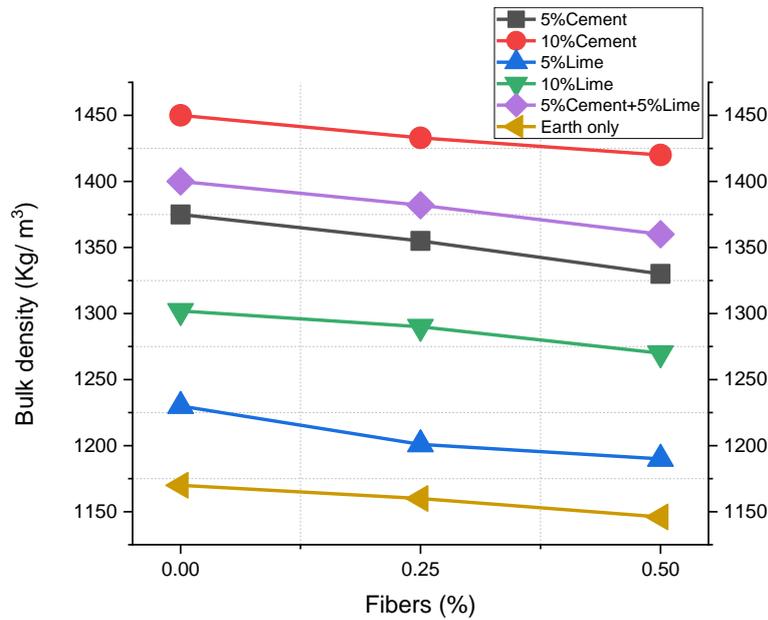


Figure 9. Block dry density of SEB at 28 days

Overall, the density decreased when the fiber quantity augmented in the mixture probably due the matrix volume occupied by the fibers which is essentially the aggregates volume. This decrease is still low where the largest decrease is 3.27% resulted in 5% cement with 0.5% fiber mixture.

### 4.4. Total Water Absorption

Total water absorption is an important property in provide the size of the total void in blocks [15]. This will provide an estimate of the overall porosity of the block. It is an indicator of water resistance where the least absorbent material is often the most effective and the most durable [28].

Figure 10 shows the variation of the water absorbed by different compounds. The results of the total water absorption capacity were confined between 11.88% and 21.39%. These results are acceptable compared to other materials results, for example 0-30% for the clay block, 4-25% for the concrete blocks [29]. The highest value for total water absorption is 21.39% recorded in the 5% lime with 0.5% fiber composition and the lowest value is 11.88% in 10% cement with 0% fiber.

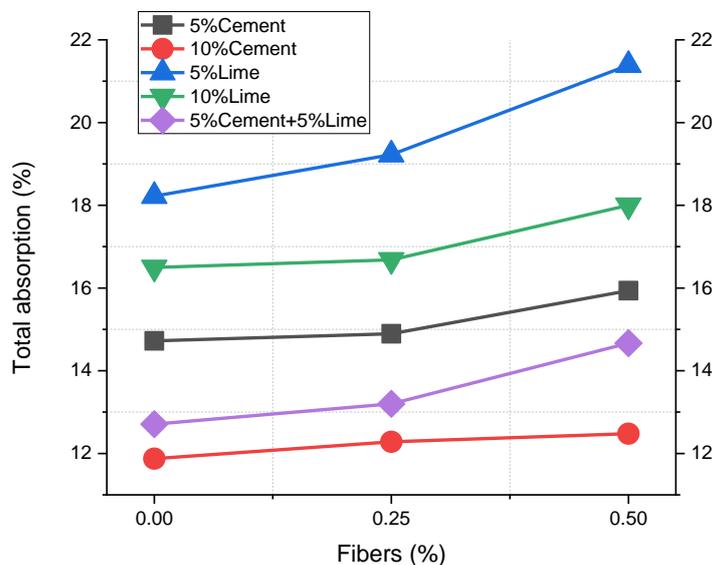


Figure 10. Total absorption of SEB at 28 days

Earth blocks stabilized with 5% and 10% cement resulted respectively the total absorption values of 14% and 11% without the presence of the fibers. However, Earth blocks stabilized with 5% and 10% lime resulted a total absorption value of 18% and 16% respectively in 0% fiber case. Thus, the increasing stabilizer quantity reduces the total water absorption. While, stabilized earth blocks with the combination of 5% cement + 5% lime resulted a better total absorption results than 5% cement, 5% and 10% lime.

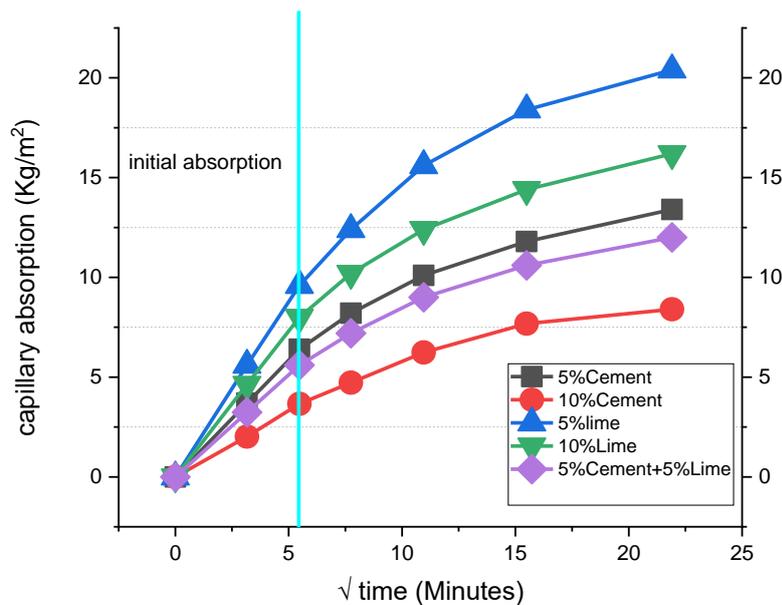
It was observed that the increase quantity fibers lead to an increase in total water absorption values. All non-fibrous compounds (0%) gave resulted a lower value for water absorption, which means that the fibers increase the water infiltration inside the blocks. This explains that the fibers have a capacity to absorb water, especially because they have a porous structure and a high hydrophilic behavior. In addition, these fibers contain a large quantity of OH compounds which is a higher water absorption property [22].

**4.5. Capillary Absorption**

Figure 12 shows the absorption graph function of time (hours), where the increasing general appearance of all the graphs is observed, which means that the pores fill up from bigger to finer. The first phase of the graph is between 0 and 30 minutes, depending on the stabilizer quantity and its effectiveness, which explains the saturation of large pores. Ideally, these pores are identified according to the initial absorption (Quantity of water absorbed from 0 to 30 minutes) [30]. The straight-line slope which is between 0 and 30 minutes is characterized by coefficient  $Abi$  ( $kg.m^{-2}.h^{-1/2}$ ) and  $Zi$  ( $mm.h^{-1/2}$ ). (1 kg of water is given  $10^{-3} m^3$ ).



**Figure 11. The test of the water capillary absorption.**



**Figure 12. Capillary water absorption of SEB (0% fiber case).**

The absorption graph in terms of time square root for all SEB samples are depicted in Figure 12. These results explain that the initial absorption takes a half an hour (0-30 minutes) which is the saturation period of the large pores

(macro-pores). Otherwise, the second phase of absorptivity (after 30 minutes) continues to fill medium and small pores. Note that the initial absorption is related to the ratio W/Binder, that is to say when the ratio W/Binder increases, the initial absorption increases too. Cement or lime stabilization collects the earth particles and bring them together by filling the pore area. It can be said that cement stabilization produces a lower absorption than lime stabilized earth. At the same time, these chemical stabilizers hinder the reorientation and the flocculation of the earth, preventing the formation of large pores and cracks [20, 31].

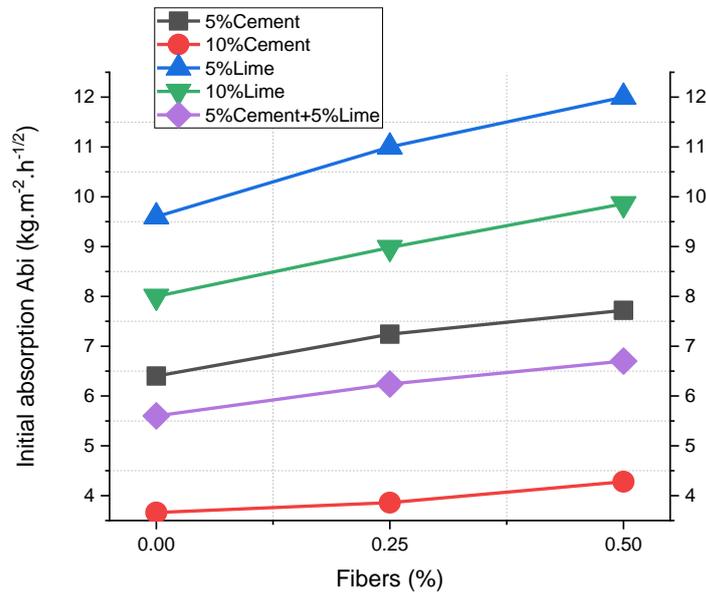


Figure 13. The effect of the fiber on the initial absorption of SEB in 28 days.

The Figure 13 shown the effect of changing the fiber quantity on the initial absorption, expressed by the absorbed water mass by the area unit in a half an hour ( $\text{kg.m}^{-2}.\text{h}^{-1/2}$ ) for different compositions. In general, when the quantity of fiber increases, the water absorbed by the capillary rise also increases for all the SEB compositions and the highest initial absorption rate when adding fibers is 25% recorded at 5% lime with a fiber quantity of 0.5%. In this case, the lowest absorption rate is 5.46% recorded at 10% cement and 0.25% fiber composition.

4.6. Porosity

Table 5. The porosity of the SEB at 28 days

Composition	Fibers (%)	The total porosity estimation (%)	The total volume porosity in water (%)	Open Porosity (%)
5% Cement	0	27.06	20.78	19.39
	0.25	28.06	21.82	21.29
	0.5	29.33	23.95	22.06
10% Cement	0	24.16	16.81	15.25
	0.25	24.99	17.57	16.08
	0.5	25.60	19.30	17.83
5% Lime	0	34.19	27.04	25.95
	0.25	35.74	29.04	28.21
	0.5	36.23	29.90	29.27
10% Lime	0	30.85	25.54	22.86
	0.25	31.33	26.40	24.94
	0.5	32.34	26.95	26.65
5% Cement + 5% Lime	0	26.15	19.61	18.67
	0.25	27.04	21.32	20.13
	0.5	28.15	22.37	20.94
Earth only	0	37.08	/	/
	0.25	37.49	/	/
	0.5	38.19	/	/

#### 4.6.1. The Total Porosity Estimation

According to Kerali [15], there is an inverse proportional relationship between density and porosity. The results of the total porosity appear in Table 5. The total porosity estimation resulted were limited between [24.99% - 38.19%], when the density decreases the total porosity increases in all the compositions. Increasing density is accompanied by compaction of particles in block and therefore less empty. The lowest value of the porosity is 24% recorded at the dosage of 10% cement without fibers and the highest porosity value is 38% recorded in the non-stabilized composition with 0.5% fiber. This can explain why non-stabilized composition has a very important W/Binder ratio, therefore a quantity of water more than necessary which can make the mixture less compact with a high porosity. The porosity of the compositions is minimized when the stabilizers quantity is added. After their chemical reaction, these stabilizers fill the pores of the matrix and improve the hardness of the structure by the formation of many bonds between particles [20]. In addition, Bogas [5] mentioned that the addition of 8% of cement and the total porosity estimation lead to a decrease from 34.7% to 29.9%.

In case of total absence of fiber when the quantities of 5% and 10% of cement is added the porosity decreases to 26.76% and 34.59%, respectively compared to non-stabilized composition (earth only), also when adding the quantities of 5% and 10% of lime the porosity decreases, respectively to 7.57% and 16.49% compared to non-stabilized composition. However, in the case of the mixture of 5% lime and 5% cement the porosity decreases about 29.19%. Thereby, concerning the effect of changing the fiber quantity on the total porosity estimation of the compositions, the results showed increased porosity proportionally to the fiber quantity increases. This proportionally is due to the increase of the air contained in the fresh earth mortar due to the introduction of fibers in the mixture shown in Figure 14.

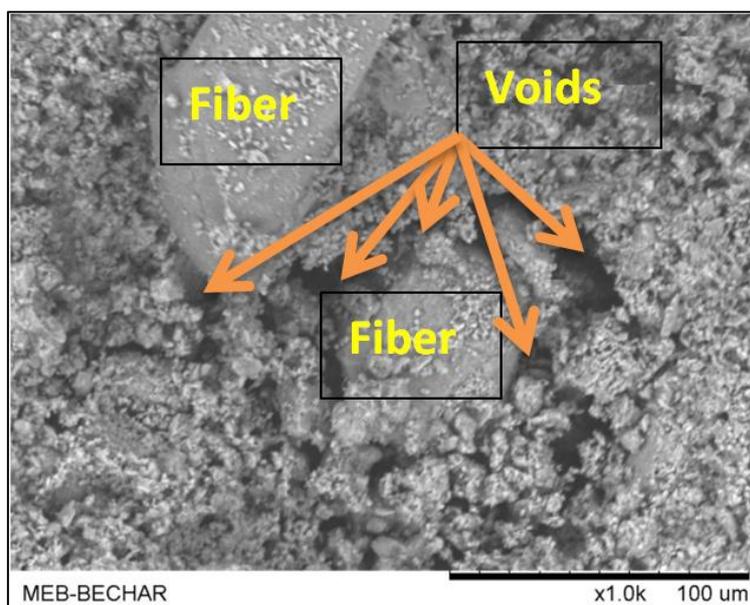


Figure 14. MEB image area matrix / fiber

These results are also confirmed by compressive strength results where the lower compression values are attributed to the increased voids created by fibers. In contrast, Namango [14] mentioned that the addition of 0 to 0.75% sisal fiber helped reducing the total porosity estimation by 33% to 28%. Similarly, Laibi [34] has proven that the addition of 1.2% of kenaf fiber increased the total porosity from 17% to 23%. This difference was carried out due to the difference in properties of the fibers or the method of implementation.

#### 4.6.2. The Total Volume Porosity in Water

The direct link between porosity and concrete quality is often mentioned in the literature [32]. The effect of changing the fiber quantity on the total porosity in water is shown in Table 5.

The highest recorded value of the porosity is 29.90%, corresponding to 5% of lime dosage with 0.5% of fiber, and the lowest value 16.81% recorded at the dosage of 10% cement without fiber. Overall, we observed that these values are lower than previous porosity values, it is explained that this porosity is specific for pores open and access to water.

The same observations concerning the quantity of stabilizers, when it increases, the value of the porosity total decreases for all the compositions. This finding was confirmed by Kerali [15], when the addition of 3% to 10% of cement reduced the total volume porosity by 26 to 14%. As the quantity of fiber increases, the total volume porosity in water of SEB increases.

### 4.6.3. Open Porosity

The open porosity value is being limited between [15.25% - 29.27%], which means that it is less than the two previous porosities. It can be suggested that these values represent open and continuous pores, or by the fact that the initial absorption comprises only a part of pores (macropores), therefore the lows and mediums pores have not yet absorbed the water.

### 4.6.4. Comparative Study

A correlation has been made between the estimate of total porosity and the quantity of fiber where the results are illustrated in Figure 15. These results showed that the correlation is positive where the correlation coefficients are: 0.996, 0.992, 0.989 and 0.984 for each of (5% cement + 5% lime), 10% cement, earth alone and 10% lime respectively. Nonetheless, these results confirmed the strong positive correlation between fiber addition and porosity increase. Furthermore, the addition of fibers influenced the shape and geometry of the pores and therefore the greater porosity.

Furthermore, Table 5 combines the results of the previous porosity values where is noted that the values of the total porosity estimation are the highest, followed by the total volume porosity in water and the open porosity; this is because open porosity only represents open and connected pores, it is therefore a porosity with the smallest values.

Contrarily, comparing the open porosity with the total volume porosity in water; the pore connection rate is thus expressed where it varies between 89.51%, 98.87%. Thereby, almost all the pores are connected which confirms that the capillary pores represented the greater part of the SEB porosity. Moreover, the fibers caused an increased connection of the pores, and consequently, reducing the resistance of the SEB to the chemical aggressions.

On the other hand, the total volume porosity in water represents only the connected and interconnected open pores and that is why it is expressed by average values. Hence, based on the comparison between the total porosity estimation and the total volume porosity in water; the rate of open pores and access to water varied from 69.59% to 84.27%, which means that the majority of SEB pores were opened and accessible to water for 24 hours.

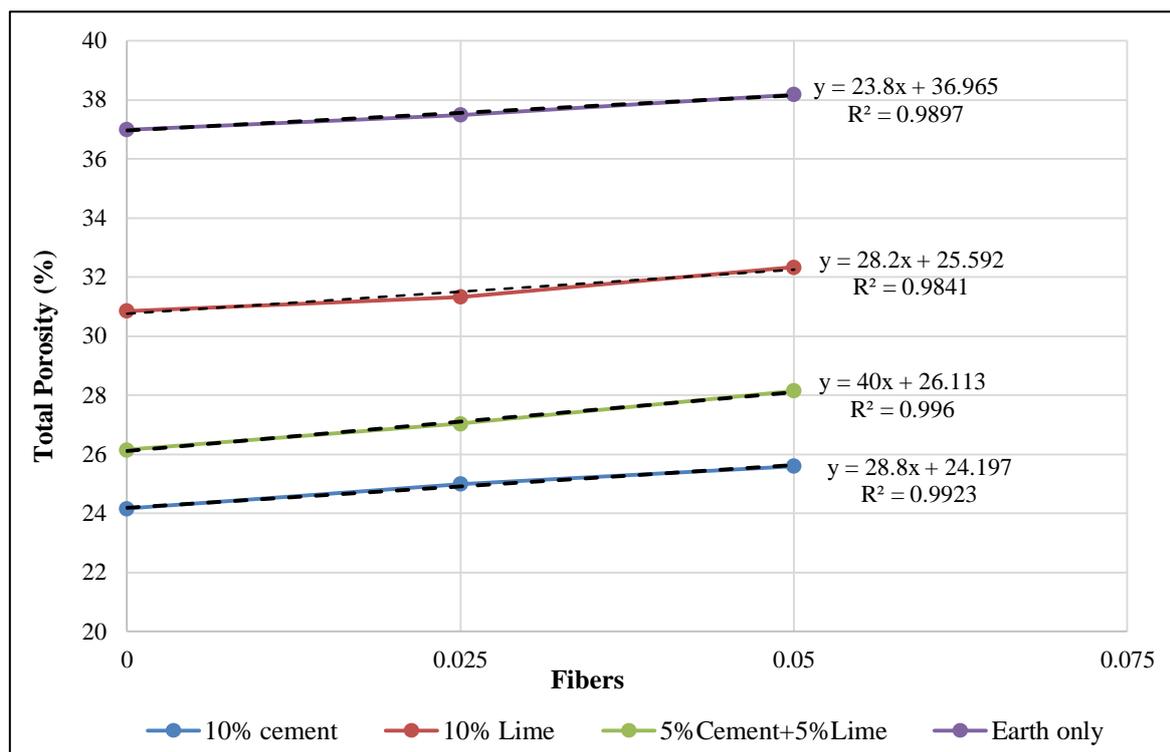
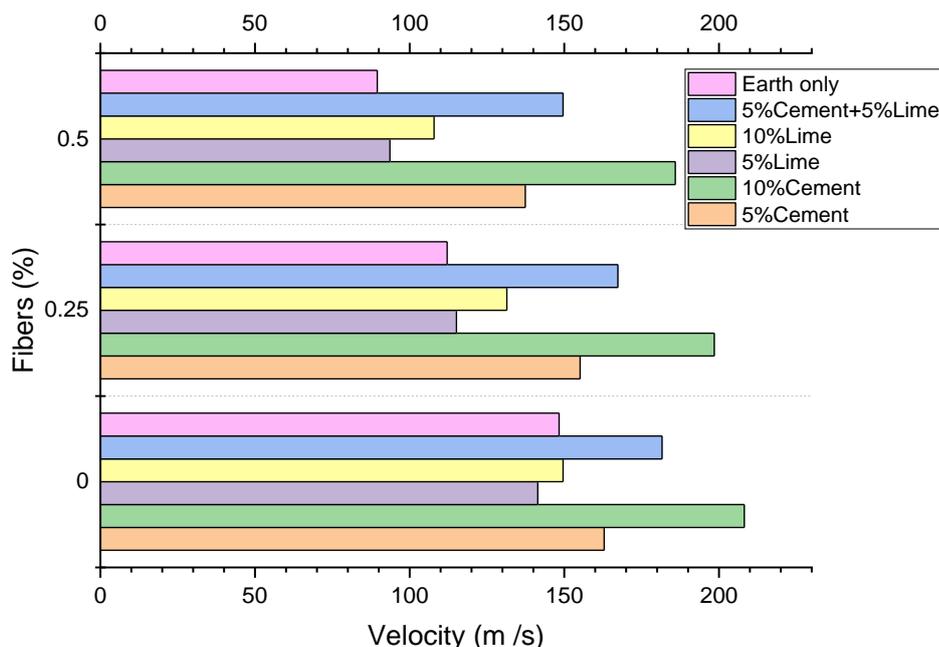


Figure 15. Correlation between the total porosity estimation and fibers

### 4.7. Ultra-sound

The speed of wave propagation is sensitive to the shape, size of pores and cracks and therefore also a very good indicator of porosity and compactness.

In this part, the influence of the quantity of fibers on the ultrasonic speed of SEB is considered. Recall that more the porosity is raised more the ultrasonic speed is decreased [33]. This means that there is a negative correlation between porosity and ultrasonic velocity.



**Figure 16. Evaluation of ultrasonic velocity versus fibers**

The results shown that the addition of fibers to the mixture caused a decrease in the ultrasonic velocity confirming the results of the previous tests. The addition of fibers modified the internal structure of the materials which means a slow wave speed due to collisions with the void pores.

## 5. Conclusions

In this study, the effect of the addition of date palm plant fibers on the porosity of (SEB) was investigated in which the most important results are:

- The addition of fibers caused voids in the matrix of the SEB.
- The compactness was completely reduced when the fiber was added accordingly the density of the SEB be reduced.
- The decrease in the mechanical strength of the SEB is the proof that the porosity rate increases because of the spaces created by the fibers.
- The addition of fibers in SEB increased the evaporation of the water, thus more water absorption, which means the increase of the total volume porosity.
- When the fibers have been added, the percentage of the connected pores increased, therefore the initial absorption value of the water also increased.
- The non-stabilized mixture was not suitable for outdoor spaces that are exposed to the water contact because its porosity was very important.
- The compositions 10% cement and the combination of 5% lime + 5% cement showed an acceptable porosity because of the chemical role of cement and lime in the stabilization.

Otherwise, the compositions of 10% cement and 5% cement + 5% lime mixtures can be used as a building material with good durability and high resistance to interference.

## 6. Conflicts of Interest

The authors declare no conflict of interest.

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