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Influence of Palm Oil Fibers Length Variation on Mechanical Properties of Reinforced Crude Bricks

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Abstract. Crude bricks are composite materials manufactured with sediments and natural fibers. Natural fibers are waste materials and used in construction materials for reinforcement. Their reuse in manufacturing reinforced crude bricks is eco-friendly and improves mechanical and thermal characteristics of crude bricks. Factors such as type of fibers, percentage of fibers, length of fibers and distribution of fibers inside the bricks have significant effect on mechanical, physical and thermal properties of biobased composite materials. It can be observed by tests such as indirect tensile strength, compressive strength for mechanical characteristics, density, shrinkage, color for physical properties, thermal conductivity and resistivity for thermal properties, and inundation test for durability of crude bricks.

In this study, mechanical and physical characteristics of crude bricks reinforced with palm oil fibers are investigated and effect of change in percentage and length of fibers is observed. Crude bricks of size 4*4*16 cm³ are manufactured with dredged sediments from Usumacinta River, Mexico and reinforced with palm oil fibers at laboratory scale. For this purpose, sediments and palm oil fibers characteristics were studied. Length of fibers used is 2cm and 3cm. Bricks manufacturing steps such as sediments fibers mixing, moulding, compaction and drying are elaborated. Dynamic compaction is opted for compaction of crude bricks due to energy control.

Indirect tensile strength and compressive strength tests are conducted to identify the mechanical characteristics of crude bricks. Physical properties of bricks are studied through density and shrinkage. Durability of crude bricks is observed with inundation test. Thermal properties are studied with thermal conductivity and resistivity test. Distribution and orientation of fibers and fibers counting are done to observe the homogeneity of fibers inside the crude bricks. Finally, comparison between the mechanical characteristics of crude bricks manufactured with 2cm and 3cm length with control specimen was made.

1 Introduction

Depletion of natural resources have drawn the attention towards the use of dredged sediments in different applications such as construction industry, infrastructure projects and land reclamation activities etc. (Rakshith and Singh, 2016). One of the possible uses of dredged sediments is manufacturing crude bricks. Crude bricks are eco-friendly construction material made with soil and natural fibers. Type of soil and percentage of clay, silt and sand are crucial for quality and strength of bricks.

Tensile strength of crude bricks can be increased considerably by incorporating natural fibers. Natural fibers of length 2 to 10 cm are commonly used for manufacturing crude bricks (Purnomo et

al., 2013) (Danso, 2016). Percentage of natural fibers is also important for crude bricks. Possible natural fibers addition ranges from 1% to 7% by mass (Ismail and Yaacob, 2011). With higher amount of fibers, thermal resistance, density and thermal conductivity of crude bricks decreases so as the strength.

Manufacturing of crude bricks consist of sediments and fibers mixing, moulding, compaction and drying. Compaction of crude bricks cane be done by static, vibratory and dynamic loading. Bricks compacted with dynamic loadings have good tensile strength (Hussain et al., 2020). For the compaction of crude bricks with normal Proctor energy, optimum water content of sediments found through Proctor test can be used for preparing sediments mixture (Bruno et al., 2018). Compaction of bricks removes the voids and increases the density of bricks. Higher density bricks have good compressive strength.

Compaction is followed with drying of crude bricks which can be done with oven or air drying. Air drying is economical and depends on the weather conditions. Lime stabilized crude bricks can be air dried in two weeks (Purnomo et al., 2013).

2 Materials and Methods

2.1. Raw materials

Dredged sediments from Usumacinta River in Jonuta, Mexico were used in this study with palm oil fibers to make crude bricks. Fibers were cut with grid of 2cm and 3cm length with knife mill. Palm oil fibers and sediments were taken from the same region of Tabasco in Mexico.

2.1.1. Usumacinta River sediments

Sediments were sampled from different locations of Jonuta town (Tabasco, Mexico). The sediments used in present study are referenced as J3-9C, where J stands for Jonuta, 3 for sampling site and 9C corresponds to the barrel number. In order to use these sediments for crude bricks, their different characteristics were studied to see their suitability for crude bricks. Some of these geotechnical characteristics are presented in Tab.1.

Tab. 1: Sediments characteristics

Sediment	Clay (%)	Silt (%)	Sand (%)	CaCO ₃ (%)	W _{opt} (%)	OM (%)	MBV (g/100g)	pH	LL (%)	PL (%)	ρ _{sed} (g/cm ³)
J3-9C	5.9	41.3	52.8	7.84	19.3	4.48	2.73	7.5	37.74	7.83	2.63

Sediments suitability for crude bricks with respect to grain size and Atterberg limits was verified through standard (AFNOR, 2001).

2.1.2. Palm oil fibers

Palm oil fibers from flowers (POFl) were cut with knife mill with 2cm and 3cm grid and referenced as POFI-2cm and POFI-3cm long fibers as shown on Fig.1a. Length distribution for 2cm and 3cm fibers was found with ImageJ software. The average of three measurements for 100 fibers by neglecting fiber powder is shown in Fig. 1b.

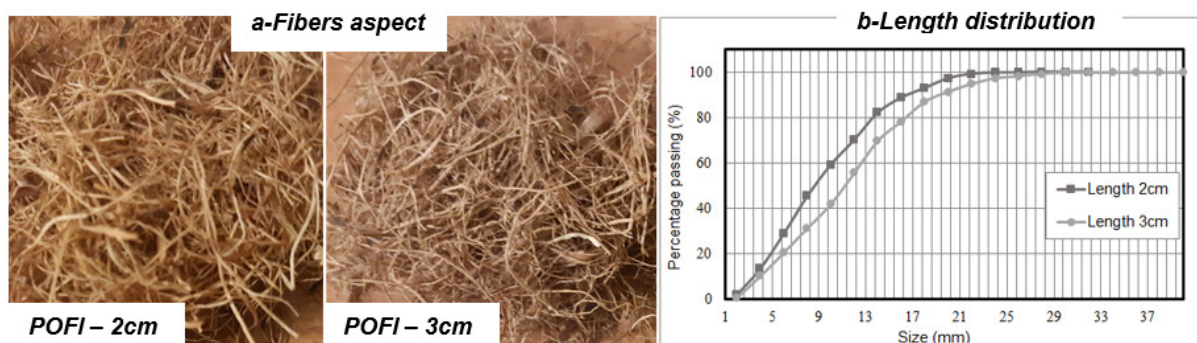


Fig. 1: View and length size distribution for 2cm and 3cm long fibers

Average tensile strength of palm oil fibers is around 119.6 MPa and cross-section area of these fibers tested with digital microscope is 0.07mm^2 (Saouti et al., 2020). Geometrical characteristics of palm oil fibers were found with ImageJ by taking image of 100 fibers on plain paper and repeating the process the three times. Maximum and the average length of palm oil fibers is given in tab. 2.

Tab. 2: Geometry of palm oil fibers

Grid size	Average length (mm)	Maximum length (mm)
2cm	9.48	24.05
3cm	11.5	32.96

From literature, tensile strength for palm oil fibers is around 110 MPa according to Danso (2016) and cross-section area of palm oil fibers ranges from 0.045 to 0.28mm^2 (Ismail and Yaacob, 2011). These values reported are similar to those of the same parameters estimated for fibers used in this study.

2.2. Crude bricks manufacturing

Initial step of crude bricks manufacturing is mixing of sediments, fibers and water. Suitable quantity of water, fibers and sediments is necessary to make good quality bricks. Percentage of water used to mix sediments and fibers was found through normal Proctor test parameters and its value is around 19.3%. Mass of fibers for different percentage of fibers was obtained with the following equation.

$$m_{\text{fibers}} = \frac{m_{\text{dry sediments}} * \% \text{ of fibers}}{100} \quad (1)$$

A mass of 450g of composite material is required for a prismatic specimen of $4*4*16\text{cm}^3$ in accordance with standard (AFNOR, 2016). Quantity of fibers needed, can be calculated from equation 1. Fibers water absorption is important for preparing appropriate mixture to made crude bricks (Purnomo et al., 2013). For this purpose, fibers were saturated before using them in crude bricks. Quantity of water for each brick was calculated with following formula.

$$m_{\text{water}} = \frac{m_{\text{dry sediments}} * \% \text{ of water}}{100} \quad (2)$$

Sediments and fibers were mixed with paint mixer to make homogenous mixture. Fibers clusters were encountered during and after mixing which were handled by continuous manual mixing, during moulding. Bricks were moulded into specimen of size $4*4*16\text{cm}^3$ according to standard (AFNOR, 2016) and compacted with dynamic loading with compaction energy of 600kJ/m^3 i.e. normal Proctor energy.

Drying pattern of bricks was determined for 40 crude bricks samples. Bricks were dried in oven at approximately $40\text{ }^\circ\text{C}$ temperature for 5 days and they were completely dried within 3-4 days. General behavior of oven drying of bricks can be observed in Fig. 2c that shows the loss of sample mass (expressed in normalized mass where M_0 is initial mass and $M(t)$ depending on time t) with time till obtained a constant mass of sample.

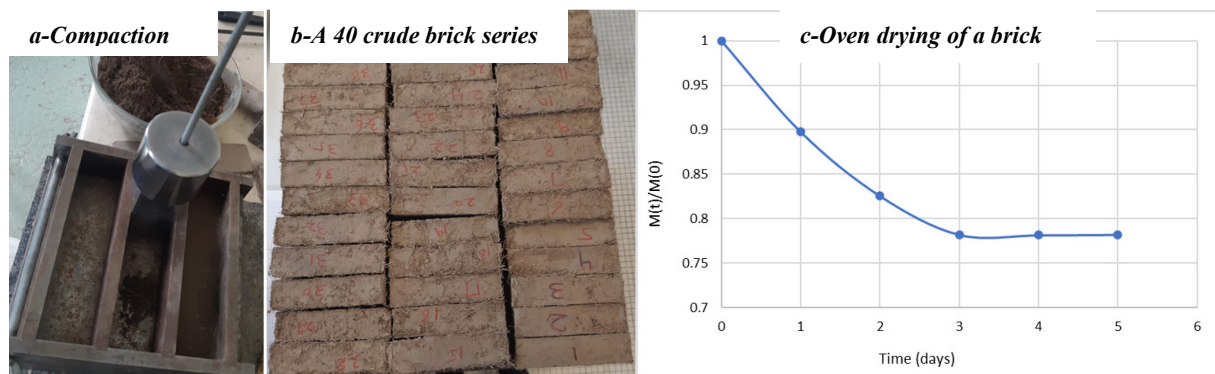


Fig. 2: Adapted compaction system, series of bricks and their mass variation with time

Average values of mass, density and linear shrinkage of 40 dry bricks series are given in Tab.3.

Tab. 3: Dimensional and physical parameters obtained on a series of dry bricks

Mass (kg)	Length (cm)	Linear shrinkage (cm)	Density (kg/m ³)
0.37	15.63	0.36	1524

2.3. Crude bricks testing

Ultra-sonic pulse velocity, tensile strength, thermal conductivity and fibers counting were done on crude bricks to determine their physical and mechanical characteristics. Testing methods are briefly detailed in below subsections.

2.3.1. Ultrasonic pulse velocity (UPV) test

UPV test was done to detect the presence of voids, cracks and nature of material. UPV was measured by direct method with PROCEQ portable ultrasonic pulse velocity meter. UPV apparatus operating on a sample is shown in Fig. 3a.

2.3.2. Mechanical testing

Indirect tensile strength of crude bricks was performed with three-point bending test according standard ASTM (ASTM D790-03, 2003). Test set up is shown in Fig. 4a.

2.3.3. Fibers distribution

Fibers distribution and cross-section area occupied by fibers was determined with ImageJ software. Bricks were divided into 6 cross sections of size 4*4 cm². Microscopic image of each section was made with digital microscope Keyence VHX 6000 model. Fig.6a shows an image of a raw sample section after cutting. These images were treated with ImageJ software to identify the fibers and their area as illustrated on Fig. 6b.

2.3.4. Thermal conductivity

Thermal measurement of two compacted 15*15*3 cm³ prismatic soil specimens made with 4% palm oil fibers by mass and 2 cm long fibers was done with heat flow method (HFM). Specimen preparation is shown in Fig.7a.

3. Results and Discussion

3.1. Ultrasonic pulse velocity (UPV) of crude bricks

UPV values for bricks with 3 cm long fibers are shown in Fig.3b. These values are average of three UPV values on same sample. The values range from 1046 m/s to 1548 m/s. They are similar to the values found in literature considering other fibers. UPV values of straw fiber reinforced crude bricks with incorporation of gypsum and slag range of 1086 m/s to 1251 m/s with different fibers percentages (Türkmen et al., 2017). In Fig.3b, for 5% fibers content, the corners of bricks were uneven due to which it was not possible to get the measurement. This problem can be avoided by carefully demoulding and handling the crude bricks during manufacturing.

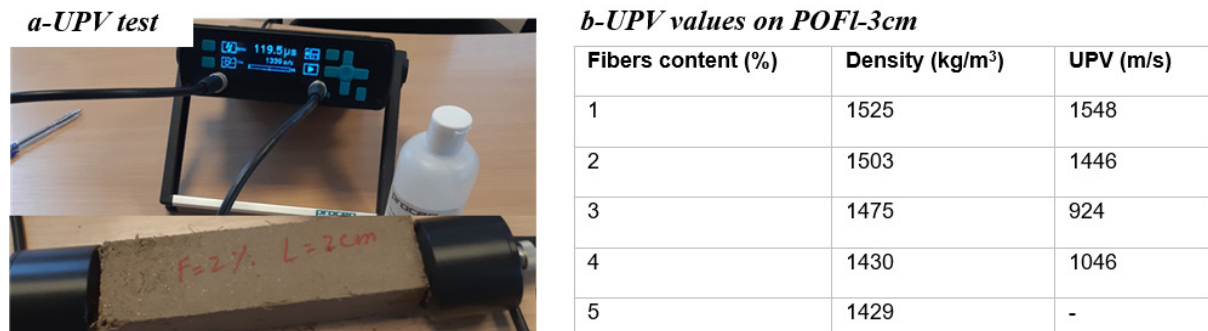


Fig. 3: Ultrasonic pulse velocity test set up and UPV values measured on crude bricks for different fibers content

3.2. Flexural strength of crude bricks

Average flexural strength results of 2 crude bricks made with 2cm and 3cm long fibers with different percentage are given in Fig. 4b. We can observe from the results obtained that with addition of 4% fibers of 2cm length and 3% fibers of 3cm length, tensile strength of bricks nears maximum of strength around 3 MPa that corresponds to an increase of 1.6 and 1.8 times respectively. In case of 1% fibers incorporation of length 2cm, the value of tensile strength 1.56* MPa is incorrect, a new series of samples will be tested.

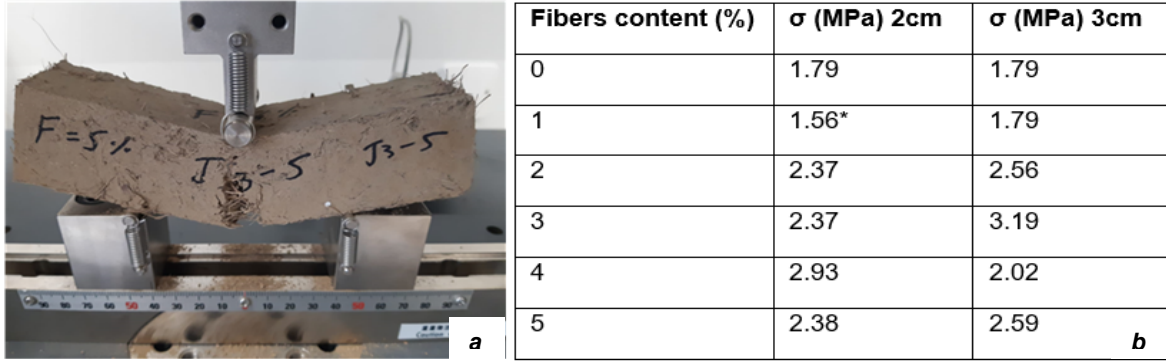


Fig. 4: Flexural strength testing for crude bricks (a). Influence of fibers content and length on strength

Load deflection curves for bricks with 0%, 1%, 2%, 3%, 4% and 5% fibers of length 2 cm and 3 cm are illustrated in Fig. 5 where F is the flexural force and the displacement recorded is the mid-point deflection.

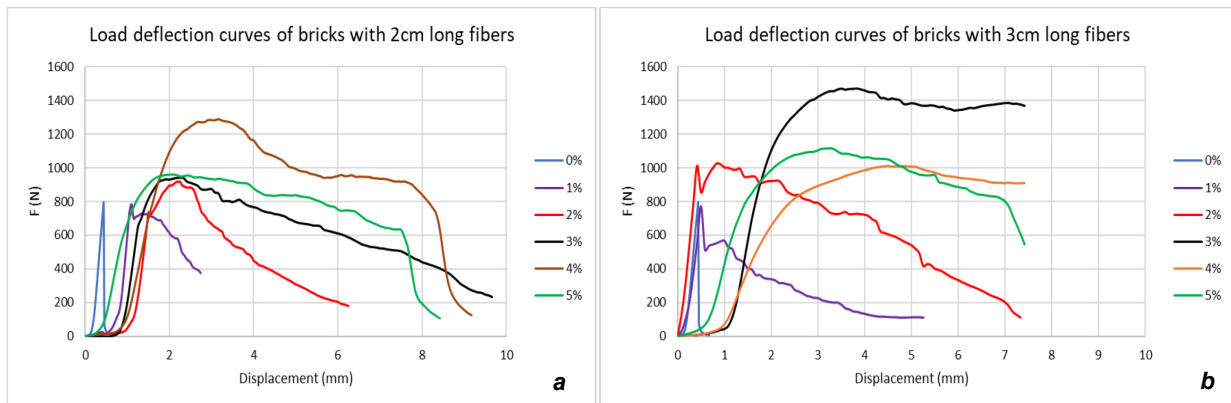


Fig. 5: Load deflection curve at different fiber content with 2cm long fibers (a) and 3cm long fibers (b)

We can observe from Fig.4 that all the bricks have strength more than 0.25 MPa which is minimum recommended limit for flexural strength of crude bricks from standard NZS (NZS 4298, 1998).

3.3. Toughness index

Toughness of crude bricks was found with by using ASTM standard ((ASTM C 1018, 1998). For unreinforced crude bricks, toughness index is 1 and increases with fibers addition. From the Fig.5, we can clearly observe that there is no post crack load bearing capacity in unreinforced bricks. The post crack load bearing capacity is increasing with increasing fiber content. Toughness index values are summarised in Tab.4.

Tab.4. Effect of fibers content on toughness index

Fibers (%)	0	1	2	3	4	5
Length= 2 cm	1	3.95	4.02	4.38	4.24	4.73
Length= 3 cm	1	2.58	4.18	4.42	3.83	3.89*

Note: * indicates one value is used for this calculation

Tab.4 shows the average of 2 toughness index values for 2cm and 3cm long fibers. The values are relatively similar and seem to be near when optimal fibers content corresponds to maximal flexural strength. Toughness index increases with increasing fiber content. From literature, crude bricks with Dunkirk port dredged sediments with 1%, 2%,3%,4% and 5% hemp shiv content have toughness values 2.42, 2.78, 2.74, 3.34, and 3.33 respectively (Hussain et al., 2020). Type of fibers and sediments significantly affect the toughness of crude bricks. Toughness index for bricks of 3cm long fibers shows clearly a maximum when 3% fibers are incorporated.

3.4. Image analysis

Number of fibers and cross-section area occupied by fibers were determined with ImageJ software. Average number of six cross sections of a brick with 3cm long fibers is 272 fibers and they cover 6.71% area of a brick cross section. In case of 2cm long fibers, average number of fibers for a cross section is 280 fibers and they occupy 6.46% area of a brick cross section. Number of fibers and area occupied by fibers in a cross section is shown in Fig. 6c. Number of fibers in case of 2cm length fibers is slightly higher due to small length of fibers. And the occupied area is slightly more in case of 3cm long fibers.

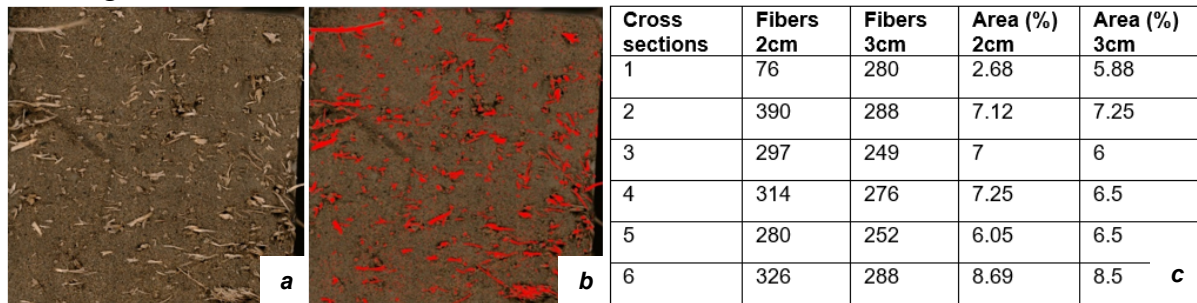


Fig. 6: Raw brick cross section (a), digitalized brick cross section (b) and number of fibers and area occupied by fibers in cross sections. In table (c), fibers content is 3% for the lengths of fibers tested.

In Fig. 6a and 6b, black shadow surfaces around the fibers at a cross section indicates the shrinkage of fibers with drying after initial swelling with water. It becomes difficult to differentiate between fibers and sediments unless the brightness and contrast of image is adjusted with ImageJ software.

3.5. Thermal conductivity

Average thermal conductivity (λ) value for brick specimens made from Usumacinta River sediments is found to be 0.23 W/m-K. This is a low value and it is considerably lower than the thermal conductivity of concrete which is around 1 W/m-K (Kanbur et al., 2013). It indicates that these bricks have good thermal characteristics. Thermal conductivity of adobe bricks ranges 0.18 to 1.13 W/m-K (Revuelta-Acosta et al., 2010) (Bahobail, 2011) (Calatan et al., 2016).

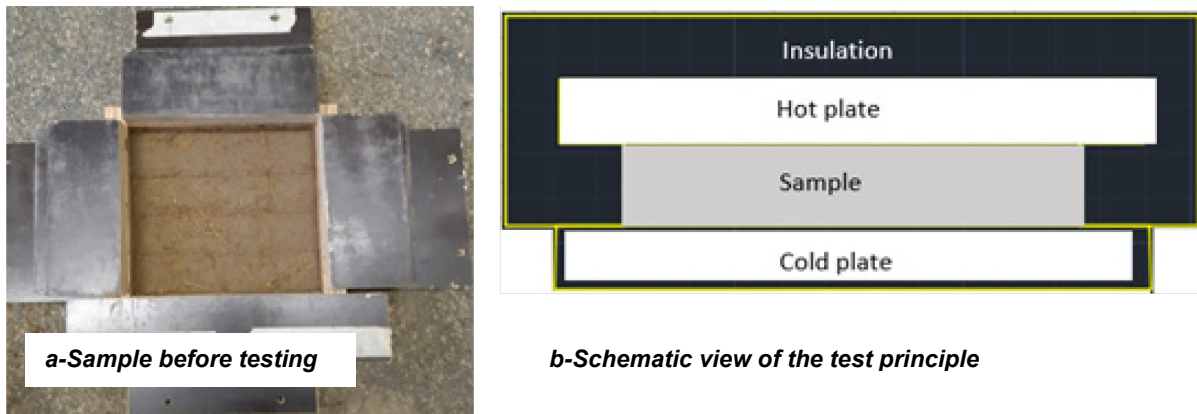


Fig. 7: Thermal conductivity $15 \times 15 \times 3 \text{ cm}^3$ specimen with 4% fibers of 2cm length (a) and scheme of testing method

4 Summary

Manufacturing crude bricks with Usumacinta River sediments and palm oil fibers constitutes a possible eco-friendly beneficial use. From the present study, the main conclusions can be drawn. A manufacturing process has been defined from preparation through molding and drying. Dynamical compaction seems to be the best method to densify crude bricks reinforced with natural fibers. Crude bricks made with river sediments and oil palm fibers have been successfully investigated. A sufficient tensile strength with 2cm and 3cm long fibers has been obtained for different fibers contents. But bricks with 2cm long fibers have optimum tensile strength at 4% fiber content while the bricks with 3cm long fibers have optimum tensile strength at 3% fiber content. UPV value decreases with higher amount of fibers as voids are induced. The use the ImageJ analysis shows that fibers occupy 6-7% area of a brick cross section. Crude bricks made with Usumacinta River sediments with addition of palm oil fibers are thermally stable, eco-friendly and have good tensile strength. To recommend fibers-reinforced crude bricks as construction materials needs to study the long-term properties and durability. Future works will consider this kind of tests to observe degradation of fibers and/or matrix under conditions of use and the possible reduction in mechanical strength.

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