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Determining the Optimum Addition of Vegetable Materials in Adobe Bricks

Gabriela Calatan[a], Andreea Hegyi[a]*, Carmen Dico[a], Calin Mircea[b]

[a]NIRD URBAN-INCERC Cluj-Napoca Branch, Calea Floresti, No. 117, Cluj-Napoca, 400524, Romania
[b]Faculty of Civil Engineering, Technical University of Cluj-Napoca, C-tin Daicoviciu Street, No. 15, 400020, Cluj-Napoca, Romania

Abstract

Housing construction technology using clay soil in various forms - paved, adobe bricks form or other - is already known and used since ancient times. Over the years, there have been numerous studies and research to improve this technology and to obtain more resistant, comfortable and durable structures. This paper presents an experimental study regarding the effectiveness of natural fiber disperse reinforcement in the adobe bricks. The results indicate an improved mechanical strength and a better thermal conductivity of the clay composite material. The variation of watched physical-mechanical parameters was influenced by the type of the used organic material, hemp fiber or straw, and of the amount entered in the mixture. By analyzing simultaneously all watched physical-mechanica parameters, for the used clay mixture, it was set an optimum addition of hemp fibers, as 9-10% percent by volume, respectively an optimal straw addition, 30-40% percent by volume.

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Keywords: sandy clay; hemp fibers; straw; adobe bricks; vernacular structures.

1. Introduction

One of the most commonly vernacular material used is the clay soil. The good behavior and the satisfactory durability of the structures made from beaten soil and adobe bricks is documented since the nineteenth century.

* Corresponding author. Tel.: +4-026-442-5462; fax: +4-026-442-5988.
E-mail address: andreea.hegyi@incerc-cluj.ro

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Known as "ADOBE BRICKS" the handmade bricks from loam, clay and sand were widely used in the past mostly for housing construction. Still from the Neolithic period, there are evidences of the existence of such constructions in areas like Mesopotamia, Anatolia and the Levant, this period is called the Age of Clay, too [11, 15, 16, 19].

Although, in the literature is reported the possibility of making the adobe bricks constructions, there are reported some shortcomings of the method, too [5 -7, 14, 17, 20]. Thus, to achieve some minimum conditions of mechanical and thermal resistance in use, it requires a thick wall; in this case, there is a high risk of cracking during drying, and, also, the axial shrinkages are significants. All these increase the risk of failure and, therefore, it is necessary workers with experience and a careful follow-up in time, especially during drying period. Bibliographic data indicate that the ideal soil for use in the intended purpose must contain at least 15-16% clay. A good workability and plasticity are essential to obtain a quality finished product. The water is required to activate the bond strength and to achieve the workability. However, too much water damages, because the drying will cause significant axial shrinkage and fissures occurrence. A linear shrinkage between 3 and 12% for blocks from soft mixtures or between 0.4 and 2%, in the case of drier mixtures is satisfactory for obtaining of finite elements without cracks [1, 7, 12, 17].

To achieve a good thermal insulation, the literature indicates a material density between 1800 - 2000 kg / m^3 [1, 7, 12, 13, 17].

In terms of mechanical strength, various design and execution codes or papers in this speciality, indicates minimum compressive strengths. For example, the New Mexico Code indicates a compressive strength of the material (the minimum needed for the achievement of the soil walls), of 2.07 N/mm^2. The Zimbabwe Code requires, for the 400 mm wall thickness, a minimum compressive strength of 1.5 N/mm^2, to the one level houses and a minimum of 2.0 N/mm^2, in the case of two-storey houses. The Australian Standard indicates a minimum compressive strength of 1.15 N/mm^2 and ASTM International E2392 / E2392M-10e1 (2010) indicates a value of 2,068 N/mm^2. The ACI Material, Journal Committee indicates compressive strength values depending on the soil composition, as follows: 2.76 to 6.89 N/mm^2 in the case of sandy soil, and from 1.72 to 4.14 N/mm^2 for clay soil [5 - 7, 12, 14, 17, 22-32].

One of the possibilities to achieve the conditions required by technical specifications is to introduce the natural fibers in adobe bricks mass to achieve a disperse reinforcement [1, 2, 3, 4, 10, 18, 21]. However, until now, is not fully documented the influence of these additions and the limits among which they are efficients. Therefore, the aim of this paper is to analyze the influence of the using of hemp fibers and straw, as addition in the bricks mass, and to establish an optimal setting of addition, so that the mechanical strength and thermal parameters to be as good.

2. Research methodology

Experimental tests were performed using a predetermined mixture of sandy clay, sand, bone glue, lime paste and water in which were introduced various quantities of hemp fibers or straw. For each composition were pursued the following parameters: workability, axial shrinkage on drying, cracking, bulk density, compressive strength and flexural tensile and heat transfer coefficient.

To achieve the experimental mixtures, it was used a soil of sandy clay type extracted from Dragan Valley, Cluj, Romania. The characteristics of grain, Table 1, in conjunction with data from the literature [5-7, 14, 17, 30] indicated that this material is appropriate to the chosen aim. The characterization of sandy clay was done by identifying the oxide composition of its, as shown in Table 2.

Table 1. Particle size distribution of used sandy clay

	sand 0,5<d<2	medium sand 0,25<d<0,5	fine sand 0,05<d<0,25	powder 0,005<d<0,05	clay d<0,005
Content (%)	37,53	20,15	16,72	18,26	7,34

Table 2. Oxide composition of sandy clay

Identified Oxide	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	PC
Concentration [%]	74,17	12,74	4,38	0,7	1,0	1,43	0,73	0,05	4,78

After conducting the preliminary tests [8, 9], it was determined the optimal composition of clay matrix: sandy clay, sand 0-4 mm, bone glue and lime paste. In this mixture, 35% represents the quantity of sand and 65% represents the quantity of binder, composed from 97% sandy clay, 1% bone glue and 2% lime paste. This was considered the control mixture, with which were compared the experimental results obtained from the mixtures containing hemp fibers or straw.

In the clay matrix were introduced vegetable materials, in varying amounts, expressed as percent by volume, relative to the clay mixture. Thus, there were introduced 3%, 8%, 9%, 10%, 12% or 15% percent by volume of hemp fiber, respectively 10%, 20%, 30%, 40%, 50% or 60% percent by volume, of straw. The hemp fibers were used as such. The straw, with a high water absorption, were used after, in advance, were immersed for an hour in water, as to avoid the water absorption phenomenon in the clay matrix.

From each thus produced mixture, were made one set of three prismatic specimens, 40x40x160 mm, for determining the bulk density, the axial shrinkage and mechanical strengths and a set of 3 specimens, slab type, 300x300x40 mm, for determining the thermal conductivity. The samples were stored in laboratory conditions until reaching the equilibrium moisture. Throughout the tests were followed the appearance and evolution of the cracks.

• the apparent density of the prepared and strengthened mixtures is determined as a ratio between the mass at the equilibrium moisture content and the volume of specimens. Results were expressed in kg/m^3.

• the axial shrinkage of the prepared and strengthened mixtures was determined using Graff aparatus, reporting the variation in the length of the specimen at the equilibrium humidity, to its original. Results were expressed in mm/100 mm.

• the flexural tensile strength, Rf, was determined by applying a concentrated load at half of the distance between the supports. On the two resulted halves of the specimen were determined the compressive strength, Rc. It has been calculated the bending strength and the compressive strength, according to equations (1) and (2).

$$R_f = \frac{1.5xF_f xl}{b^3} N/mm^2 \quad (1) \qquad\qquad R_c = \frac{F_c}{1600} N/mm^2 \quad (2)$$

where:

R_f - bending strength (N/mm^2), b – the side of the prism square section (mm) F_f - the failure load applied in the middle of the prism (N), l - distance between supports (mm)

R_c - compressive strength (N/mm^2), F_c – the failure load (N), 1600 = 40x40 mm – platens area or auxiliary plates (mm^2).

• The thermal conductivity was determined based on the heat transfer property of the samples with a thermofluxmetric method for an average temperature between plates, of 10ºC. The sample, dried in an oven till to a constant mass, was placed in the apparatus for determining the thermal conductivity. The sample thickness was measured automatically by the apparatus. It was recorded the thermal conductivity of the specimen.

• The workability of the mixture was followed during mixtures preparation and specimens manufacturing.

• During the drying, till to achieve moisture balance, it was visually tracked the appareance and the development of cracks.

3. Results and discutions

The obtained experimental results are shown in Figures 1a, 1b and 1c.

Because in the clay matrix were introduced additions (bone glue and lime paste), its density was slightly below the minimum limit of 1800 kg/m3, indicated by the literature as the recommended minimum thermal mass convenient, Figure 1. This inconvenient, in terms of thermal efficiency, was compensated by the introduction of vegetal materials. Although the density decreases with increasing of hemp fiber content, the flexural tensile strength increases continuously and the compressive strength has a Gauss evolution.

The composition containing 10% hemp fibers represent an inflection point on the evolutionary chart of compressive strength. Specifically, an addition of hemp fibers greater than 10% will cause not an increase, but a reduction in compressive strength, tensile strength by bending even continue to grow. This behavior has been attributed to the fact that probably a higher content of hemp fibers, specimen mass suffering a decrease compactness, being probably sufficient to cover the clay matrix fibers. This assumption was supported by the reduction mixture workability as the amount of hemp fibers in the mixture increased. In between 9% -10% hemp fiber added was observed that mechanical strengths grow sharply and steadily reducing bulk density decreases.

Specifically, an hemp fibers addition, greater than 10%, will not cause an increase, but a reduction of compressive strength, although, the bending tensile strength continue to grow. This behavior has been attributed to the fact that probably for a higher content of hemp fibers, the specimen mass suffering a compactness decrease, being probably insufficient clay matrix, to cover the fibers. This assumption was supported also, by the reduction mixture workability, as the amount of hemp fibers in the mixture increased. In the range between 9% -10% of added hemp fiber, it was observed that the mechanical strengths grow sharply and the bulk density steadily decreases.

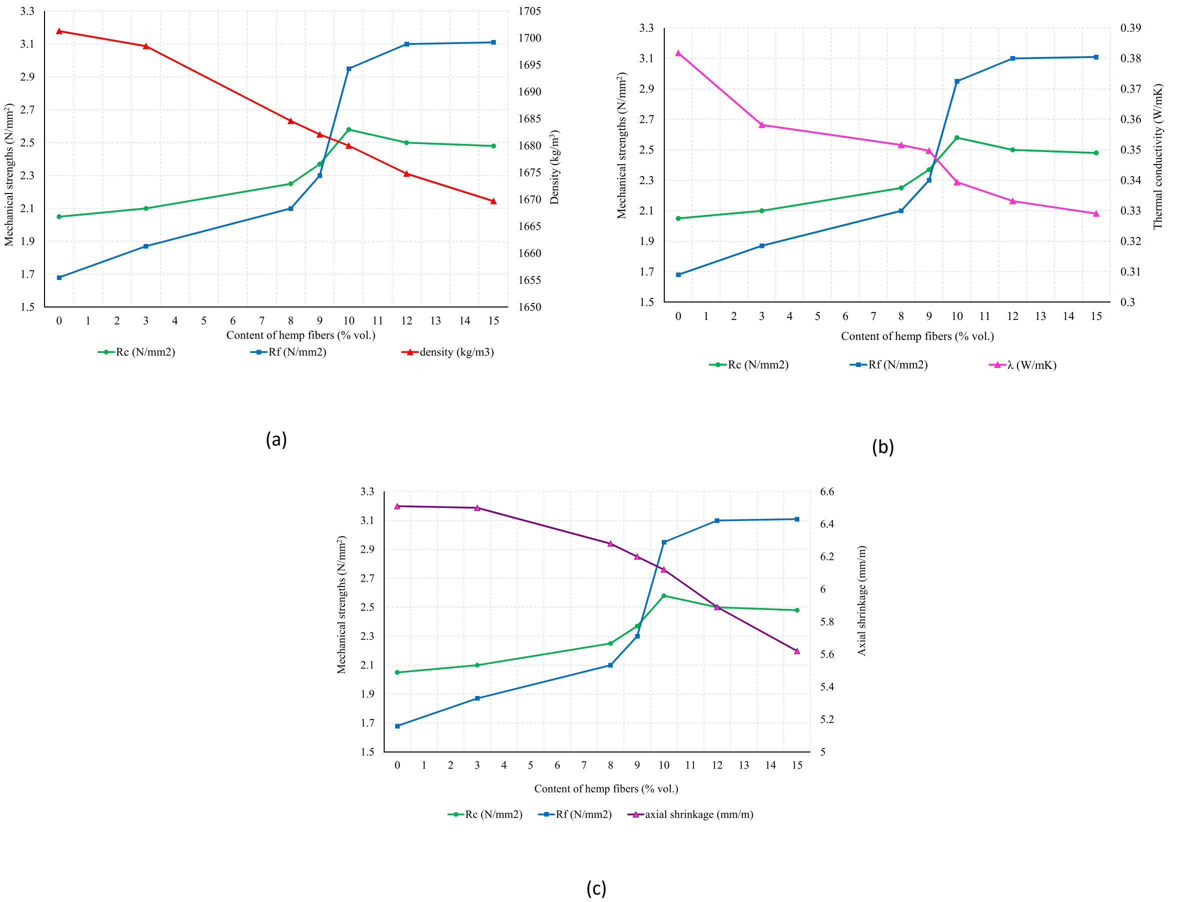


Fig. 1. Variation of compressive strength, of flexural tensile strength, of bulk density, of thermal conductivity and of axial shrinkages depending on the amount of hemp fibers from a clay mixture

On the other hand, with increasing of hemp fiber content, the thermal conductivity steadily decreases, Figure 1b. Through this, we can say that although the density is below the lower limit of the indicated range by the literature, regarding of thermical point of view, the material behavior improves by adding of hemp fibers. Similarly, the increasing of the hemp fiber content in the mixture, determines an improvement of the material performance in terms of reducing axial shrinkages, Figure 1c.

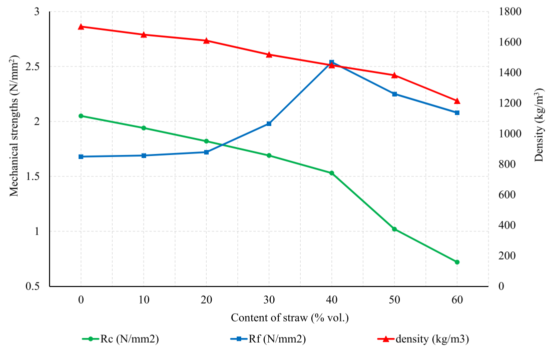
To establish an optimal content of hemp fibers, were summed the experimental results obtained for mechanical strengths, density, thermal conductivity and axial shrinkage. Because, it wants mechanical strengths as high, thermal conductivity and axial shrinkage as low, it was found that an addition of 10% hemp fibers is the maximum that it can be added in this type of clay matrix, larger quantities of hemp fibers causing a reduction of the compression strength. Analyzing the decreasing graphics slopes for bulk density, thermal conductivity and axial shrinkage and growth graphics slopes of mecanical strengths, depending on the amount of hemp fibers in the mixture, it was found that the optimal addition of hemp fibers is in the range of 9-10% volume percent.

The test specimens made of these mixtures did not have cracks during drying.

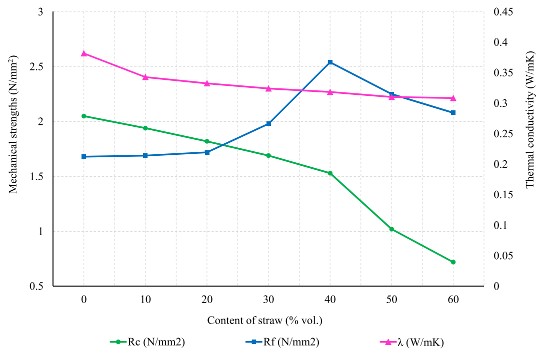
A similar analysis was performed also, for clay mixtures, where straw were introduced. It observes a lower bulk density, Figure 2a., reducing of the thermal conductivity coefficient, Figure 2b and of the axial contractions, Figure 2c, with increasing of straw content in the mixture.

Unlike the clay compositions with hemp fibers, for those with straw, the compressive strength decreases continuously with increasing of straw content. This behavior was attributed to the relativ tubular and rigid shape - brittle of the straw, which has determined a content with much larger goals in tested specimens, compared with the witness specimens or with the hemp fiber mixtures. On the compressive strength graphic, depending on the content of straw in the mixture, it is observed a critical point, at 40% content of straw. Although, up to this value, the compressive strength decreased continuously, from this point, this indicator has a more rapid decline, indicated by the steeper slope of the line $R_c = f$ (% straw) for the values of 40%, 50%, 60%.

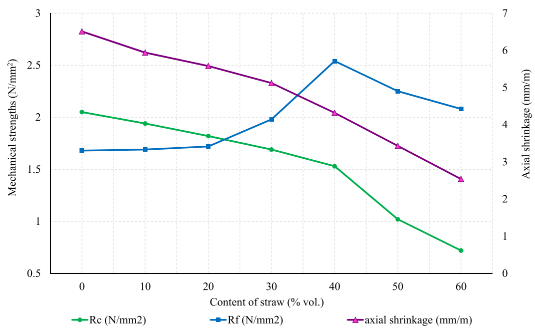
The bending tensile strength is improved by the addition of straw in clay matrix, reaching a maximum for the composition with 40% straw. A straw addition greater than 40%, resulted in a rapid decrease of bending tensile strength.



(a)



(b)



(c)

Fig. 2. Variation of compressive strength, flexural tensile strength, bulk density, thermal conductivity and axial contractions depending of the straw amount in clay mixture

Therefore, in terms of mechanical strengths performance (compression and bending tensile strength), it is appreciated that 40% percent by volume (straw in clay mixture) is the maximum amount indicated to be used in this case. Because we wanted a density as close to the limit indicated in the literature, low shrinkage as well, but a thermal conductivity as small as, too, finally it was appreciated that the recommended amount of straw into mixture is in the range of 30% - 40% by volume, in this area is the largest increasing of flexural tensile strength, while the compressive strength is the lowest. Setting of this range was supported also by the good workability of the mixture. Additionally, in time, it was observed that for straw amounts more than 40%, it occurs rotting phenomenon of the straw. The test specimens made of these mixtures did not have cracks during drying.

The recorded values for thermal conductivity of mixtures considered optimal, both with hemp fibers addition and in the case with straw addition, were compared with the thermal conductivity of several building materials [33], as shown in Figure 3. Thus, for clay mixtures with 9-10% fiber hemp addition, percent by volume, respectivly with 30-40% straw addition, percent by volume, it was considered that they are similar (from the thermal conductivity point of view), with natural aggregate concrete, with perlite concrete or with granulite concrete with a density of 1000 kg/m^3, or with BCA masonry elements, type GBN 50.

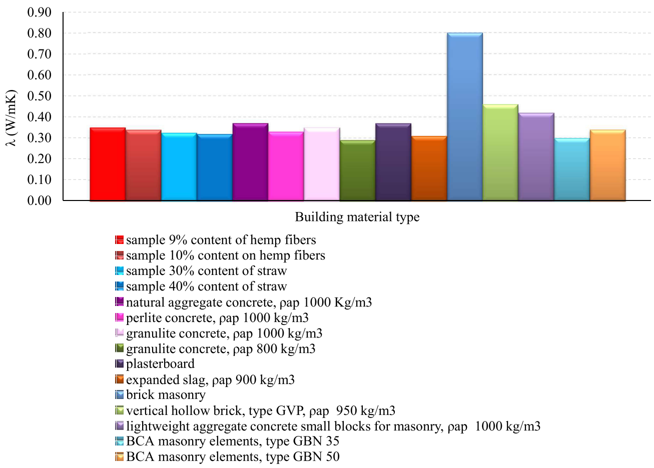


Fig. 3. Comparative representation in terms of thermal conductivity of the clay mixtures (considered optimal) with various building materials

4. Conclusion

The paper shows a way of determining an optimal vegetal materials addition, hemp fiber or straw, while considering the main factors that should be followed to achieve the sandy clay bricks: axial contractions, absence of cracks, bulk density, mechanical strengths and thermal performance. Thus, the paper contributes to the completion of information in the field, reported so far in the literature and indicates the possibility of dimensional reducing of the soil walls, keeping the reliability characteristics and those of thermal efficiency.

The experimental results showed the reducing of workability, of shrinkage, of bulk density, of fracture risk and of thermal conductivity, as the amount of vegetal material increases in the mixture.

In the same time with increasing the amount of vegetal material in the mixture, in terms of mechanical strengths, it is observed a variation that can not be defined by a constant tendency. Thus, the increase of hemp fiber content causes a Gauss variation of compression resistance and a continuos increasing of bending tensile strength. The increase of straw content causes a reduction in compressive strength and a Gauss variation of bending tensile strength. Therefore, analyzing simultaneously all parameters for the used clay mixture, it was set an optimum addition range of hemp fibers, of 9-10% percent by volume, respectively an optimal straw addition, of 30-40% percent by volume. In terms of thermal conductivity, it was appreciated that these clay mixtures are comparable with natural aggregate concrete, with perlite concrete, with granulite concrete with a density of 1000 kg/m^3, or with brick masonry elements BCA, type GBN 50 and they are comparable also, with the reported experimental results of other studies in the literature. In terms of mechanical strengths, experimentally obtained, they are comparable with the experimental results reported by other studies in the literature [3, 4, 10, 18, 21].

This paper presents a technology of "Green buildings technology" type, which requires a minimum consumption of non-renewable natural resources and energy, allowing the use of local materials and vegetable waste and largely eliminating the potential polluter of classical, industrial production.

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