HEAT TRANSMISSION THROUGH WALLS OF COMPOSITE MATERIAL WITH CLAY MATRIX
/
TRANSMITEREA CALDURII PRIN PERETI DE MATERIAL COMPOZIT CU MATRICE DE LUT

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ABSTRACT
The article presents results obtained for the thermal characterization of composite materials with clay matrix and inserts from agricultural waste (MCMLIDA). The experiments carried out led to the estimation of the coefficient of thermal conductivity of the bricks made from the MCMLIDA composite material. MCMLIDA composite materials have physical properties dependent on the parameters of the manufacturing process, one of the most important being the concentration of the insert. MCMLIDA materials were tested for eleven insert concentrations and four types of inserts (maize cobs, walnut husks, wheat straw, wool). Only the materials with the first two types of inserts had the necessary cohesion for the experiments over the entire range of concentrations (0-50%). It was found that the values of the conductivity coefficient of those materials were between 0.4 and 0.8 W/(mK), values that placed them in the area of good insulating materials from a thermal point of view. It was also observed that thermal conductivity increased (along with a decrease in insulating capacity) as the amount of insertion in the matrix was increased.

REZUMAT
Articolul prezinta rezultate obținute pentru caracterizarea termica a materialelor compozite cu matrice de lut şi inserții din deșeuri agricole (MCMLIDA). Experimentele efectuate au condus la estimarea coeficientului de conductivitate termică a cărămizilor fabricate din materialul compozit MCMLIDA. Materialele compozite MCMLIDA au proprietăți fizice dependente de parametri procesului de fabricare, unul dintre cei mai importanți fiind concentrația inserției. Au fost testate materialele MCMLIDA pentru unsprezece concentrații ale inserție si patru tipuri de inserție (tocătură de coceni de porumb, tocătură de coji de nuca, tocătură de paie de grâu, lână). Numai materialele cu primele doua tipuri de inserții au avut coeziunea necesara experimentelor pe tot intervalul de concentrații (0-50%). A fost constatat ca valorile coeficientului de conductivitate al acestor materiale sunt cuprinse intre 0.4 si 0.8 W/(mK), valori care le situează in zona materialelor bune izolatoare din punct de vedere termic. De asemenea, se constata creșterea conductivității termice (odată cu scăderea capacitații izolatoare) pe măsură ce este sporită cantitatea de inserție in matrice.

INTRODUCTION
According to some research, *(Popa et al., 1986; Vladea, 1974)*, heat transfer is the field of thermodynamics that deals with heat energy exchanges between bodies. Heat transfer occurs under the influence of a temperature difference. The second law of thermodynamics in Clausius's formulation states that this transfer takes place by itself only from the higher temperature to the lower temperature. Also, according to the mentioned research, the three heat transmission mechanisms are: conduction, convection and radiation. Thermal conduction is one of the ways of transmitting heat between two media at a certain temperature difference, in which, unlike convection and radiation, energy transfer occurs through collisions between neighboring elementary particles, close to close, throughout the mass of the environment.

Although, as shown in other paper, (*Gavrila, 2000*), in most cases encountered in practice, heat transmission is carried out simultaneously through two or all three of the mentioned mechanisms, but in the present paper, the heat loss will be analyzed only through conductivity.

For the composite materials used in the field of construction and not only, the phenomenon of heat transmission is very important.

Sometimes thermal insulation is followed, other times conductivity through the walls built from composite materials common in civil constructions. The physical properties, and especially the thermal ones, have been studied for composite materials with clay matrices, clay, silts, etc. (*Lertwattanaruket et al., 2011; Florescu et al., 2019; Quagliariniet et al., 2015; Abanto et al., 2017; Calatan et al., 2020).*

Calatan et al., (2020), even studied the optimal proportions of clay and sand in the mortar, in order to obtain a maximum resistance to bending for bricks, but also a satisfactory thermal insulation. Paper and cellulose residues were used to make adobe bricks (*Muñoz et al., 2020*). Compression resistance was increased by up to 190%, thermal conductivity was reduced by up to 30%, water resistance was increased so that the standards were respected, and toxicity values decreased by up to 20%. A mathematical model with finite elements for a wall built with adobe bricks was presented by *Tarque et al., (2010*), but the model was only mechanical and not thermomechanical. It is, however, a starting point for the construction of elementary thermomechanical models. Measuring thermal conductivity is not an easy problem to solve, as *Mosquera et al., (2014*), showed. They estimated the effective thermal conductivity of an adobe using a theoretical and a theoretical-empirical method. It showed that only in five cases out of eighteen, the results of the two paths were close enough. *Zhengrong et al., (2024*), argued that the durability of 3D printed buildings had attracted increasing attention in research. As a basis for evaluating energy efficiency and sustainability, it is crucial to consider the thermal performance of 3D printed walls during the structural design phase. 3D printed walls exhibit anisotropic thermo-physical properties and complex heat transfer processes. For such a model, information about dimensions, directions and properties is essential. The mathematical model is one of a thermal network suitable for objects with changing directions of thermal conductivities. Numerical simulation of the anisotropic 3D printed wall with complex geometry shows that the reinforced structures and cavities cause alternating surface temperature distributions with an average temperature difference of about 0.75°C. Due to the barrier effect of the inclined printed structure, the triangular cavities show higher temperatures than the square cavities. The proposed model is significant for characterizing the relationship between structure and thermal performance and can be used to optimize the thermal design of 3D printed walls. It is shown that the thermal insulator performance of the structure can be significantly improved by using less material and reducing the mass/weight. *Araújo et al., (2022)*, manufactured lightweight 3D printed cement composites by replacing traditional fine aggregates with slightly expanded clay aggregates to improve thermal insulation. The 100% replacement led to a decrease in thermal conductivity from 1.19 W/mK, to 0.68 W/mK. A theoretical model combined with an operational solution using the MATLAB program, for heat transmission of heat through any wall, was given by *Mižáková et al., (2021*).

In this article, experimental results are given regarding the conductivity coefficient for composite materials with clay matrix and inserts of shredded corn husks, respectively shredded walnut husks. Also, theoretical and empirical solutions are proposed for the heat flow through the adobe wall and for the amount of heat transmitted through an adobe wall of a given area. A numerical solution with finite elements is given using the facilities of the MATLAB program, for the temperature distribution on the section perpendicular to the side faces of the wall.

MATERIALS AND METHODS

In order to estimate the heat transfer (thermal energy) through the walls built from composite materials with clay matrix and agricultural waste, the theory of heat transfer is used together with the results of experiments measuring the conductivity coefficient. Using the results of this method with two main components, formulas for particular cases, partially extrapolable, are obtained.

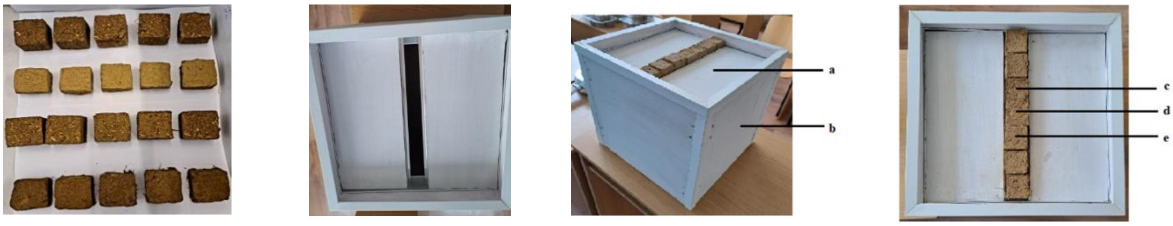
The theory of heat transfer through the wall of composite material is taken from some works (*Popa et al., 1986; Vladea, 1974; Gavrila, 2000; Gavrila, 2003*). The simplest possible model is approached to be able to observe the consequences of the introduction of inserts from agricultural waste in relation to the material from pure clay or other construction materials.

The experimental results from which the values of the thermal conductivity coefficient resulted were made within the applied research of the authors regarding the uses of the above-mentioned composite materials.

Bricks of composite material with dimensions 40x40x30 mm, made of composite material with clay matrix and inserts from agricultural waste (shredded corn cobs, walnut shell and wheat straw, respectively wool waste), figure. 1a, were mounted in the slot (fig. 1b) of a box with plasterboard walls, as can be seen in Figure 1c.

Inside the box, a source was inserted that provided a good approximation of the internal temperature of 100ºC. Knowing the thermal conductivity coefficient of the plasterboard and taking into account the temperatures measured on the external surfaces of the box (on the plasterboard surface and on the external surface covered with composite material bricks), the coefficient of thermal conductivity of the composite material with which the box slot was covered was deduced, in points on its longitudinal axis.

Calculation relations from sources were used (*https://www.scrigroup.com/casa-masina/constructii/TRANSFERUL-DE-CALDURA-IN-CONST22834.php#google_vignette*; *https://www.baduc.ro/fise/2601001019.pdf; https://construiestesingur.wordpress.com/2010/12/15/ce-este-conductivitatea-termica-%CE%BB/; https://ro.wikipedia.org/wiki/Conductivitate_termic%C4%83*).



a b c d

Fig. 1 - The components of the experimental system

a - bricks made of composite material; b - box with a slot made for moving the bricks;
c - bricks mounted in the slot of the box with the heat source, ready for measurement;
d - measurement points on the brick wall.

The composite materials with an insert of chopped walnut shells showed satisfactory cohesion in the range of insert concentrations 0-50%. The material with an insert of straw shredding showed cohesion only up to an insert concentration of 15%, and the material with an insert from wool waste only up to a value of 10% of the insert concentration.

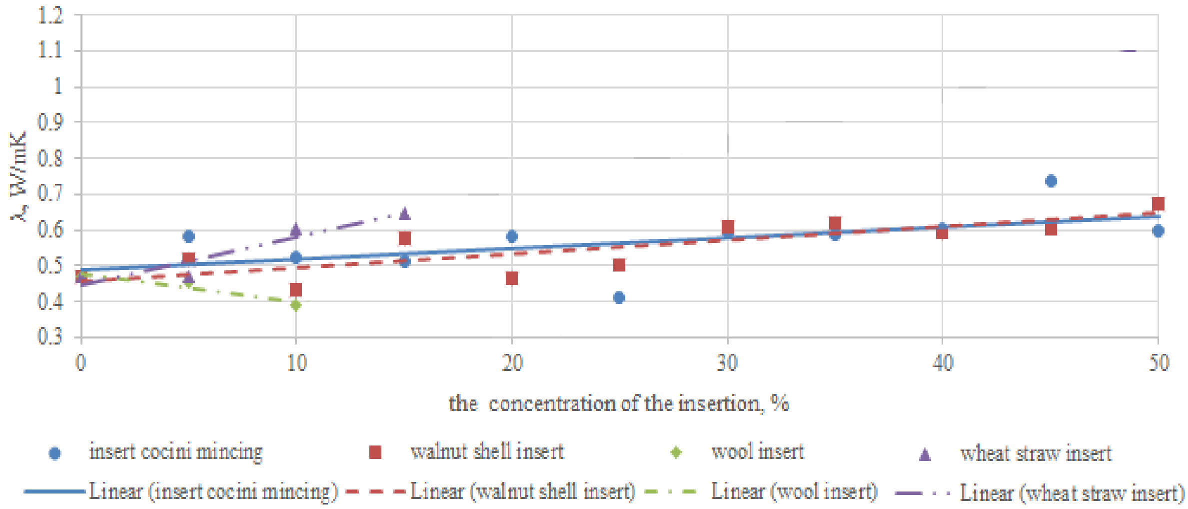


Fig. 2 - The variation of the thermal conductivity coefficient for the four types of composite materials, depending on the concentration of the insert

After a minimum statistical processing, the thermal conductivity coefficient values were obtained, specified in the graphic representation in Figure 2. Knowing the constant temperature inside the box, T_{ic} =100ºC, generated by an electrical resistance, for calculating the heat flow through the walls, q (it was assumed that the thermal energy was transmitted outside the box only perpendicular to the walls), the relations (*https://www.scrigroup.com/casa-masina/constructii/TRANSFERUL-DE-CALDURA-IN-CONST22834.php#google_vignette;https://www.baduc.ro/fise/2601001019.pdf; https://construiestesingur.wordpress.com/2010/12/15/ce-este-conductivitatea-termica-%CE%BB/; https://ro.wikipedia.org/wiki/Conductivitate_termic%C4%83*) are valid:

$$q = \lambda_R \frac{T_{ic}-T_a}{g_{ps}} = \lambda_R \frac{T_{ic}-T_b}{g_{pl}} = \lambda_c \frac{T_{ic}-T_c}{g_c} = \lambda_d \frac{T_{ic}-T_d}{g_c} = \lambda_e \frac{T_{ic}-T_e}{g_c}, [\mathrm{W/m^2}] \quad (1)$$

where: q - heat flow through the walls, W/m^2;

λ_R – thermal conductivity of the box, W/(mK);

$\lambda_{c,d,e}$ – thermal conductivity in points c, d, e, W/(mK);
T_{ic}– the temperature inside the box, ºC;
T_a – the temperature measured at point a, ºC;
T_b – the temperature measured at point b, ºC;
T_c – the temperature measured at point c, ºC;
T_d – the temperature measured at point d, ºC;
T_e – the temperature measured at point e , ºC;
g_{pl} – side wall thickness (gypsum), mm;
g_{ps} – upper wall thickness (gypsum), mm;
g_c – composite material thickness (brick), mm.
From equalities (1), relations (2) result:

$$\lambda_c = \lambda_R \frac{g_c}{g_{pl}} \frac{T_{ic} - T_a}{T_{ic} - T_c}, \quad \lambda_d = \lambda_R \frac{g_c}{g_{pl}} \frac{T_{ic} - T_a}{T_{ic} - T_d}, \quad \lambda_e = \lambda_R \frac{g_c}{g_{pl}} \frac{T_{ic} - T_a}{T_{ic} - T_e} \ \ [\mathrm{W/(mK)}] \tag{2}$$

The average thermal conductivity coefficient, λ_C, was obtained by averaging the conductivity coefficients determined in points c, d and e, according to equality (3):

$$\lambda_C = \frac{\lambda_c + \lambda_d + \lambda_e}{3} \ \ [\mathrm{W/(mK)}] \tag{3}$$

Figure 2 shows the most important information: the thermal conductivity coefficient values for each of the 4 materials and the trend line. Thus, it is shown that for 3 of the 4 materials, the conductivity coefficient increased with the insertion concentration. Therefore, for sufficiently studied materials, the thermal insulation decreased with the increase of the insertion concentration.

The thermal conductivity coefficients were calculated according to the formulas (1-3) that can also be found in the paper of *Dobritoiu, (2024)*. These formulas use the thickness of the walls of the box in which the heat source is located and the coefficient of thermal conductivity of the gypsum wall, as well as the temperatures measured at three points on the surface of the composite bricks. The last measured data can be found in the same source (*Dobritoiu, 2024*).

The technology of obtaining the bricks, their behavior over time (dimensional and appearance changes), the mechanical tests (bending stress and compression stress) as well as the statistical processing of the results were described by some authors. Following the research carried out, the results obtained on composite materials with clay matrix and agricultural waste insertion (nut shells, cobs, wheat straw, wool) will be compared with other biodegradable and sustainable composite materials, such as those with mud matrix and sawdust/seed husk insert (*Surdu, 2023; Farcas-Flamaropol, 2023*).

In order to summarize the above, the technological flow diagram - thermal conductivity determination figure 3 was drawn up, for the composite materials with clay matrix and agricultural waste insert.

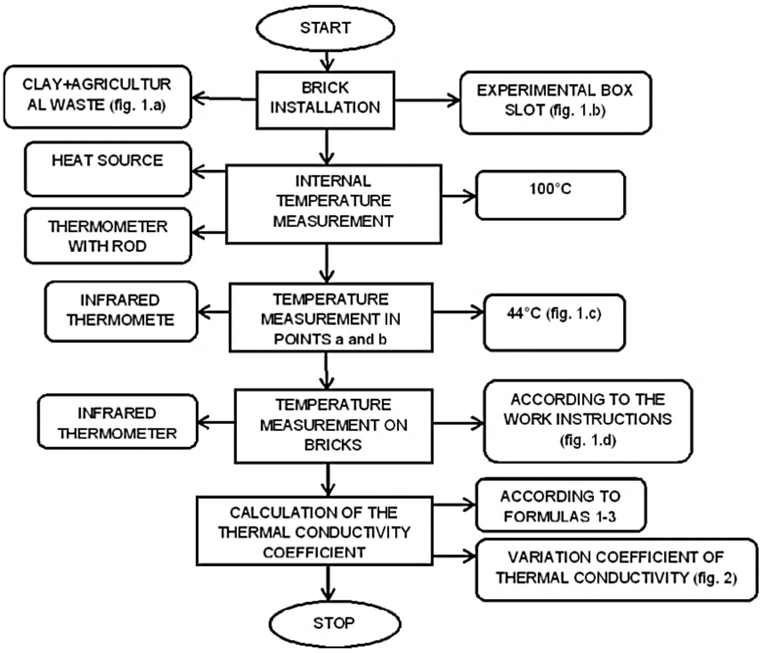


Fig. 3 - Diagram in technological flow - determination of thermal conductivity

RESULTS AND DISCUSSION

1. Heat loss through plain walls

The first approximation of heat loss through a MCMLIDA brick wall was made according to *Gavrila, (2003)*, assuming that the homogeneous plane wall had an infinitely long length, in relation to the thickness δ. It was assumed that the heat transfer was unidirectional along the Ox, axis, perpendicular to the wall surface. The conductive thermal transfer equation, in steady state, became a differential equation with simple partial derivatives *(Gavrila, 2003):*

$$\nabla^2 T = \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = 0 \tag{4}$$

For the three-dimensional case, x, y, z were the coordinates of the generic point in the wall space. For the 1- dimensional case, equation (4) became an ordinary, elementary differential equation:

$$\frac{d^2 T}{dx^2} = 0 \tag{5}$$

with the conditions at the limits of the interval (the limits of the wall along the axis Ox):

$$\text{for} \quad x = 0, T = T_1, \text{ for } x = \delta, \ T = T_2 \tag{6}$$

Schematization of the geometry of the model is given in figure 4.

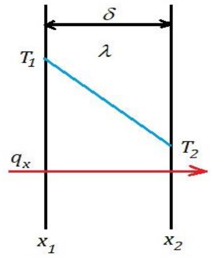


Fig. 4 - The geometry of the ideal wall for the elementary mathematical model of heat transmission through conduction, after the work *(Gavrila, 2003)*

The general solution of the differential equation (2) was:

$$T = k_1 x + k_2 \tag{7}$$

The integration constants k_1 and k_2 were found using the boundary conditions (6):

$$k_1 = \frac{T_1 - T_2}{\delta}, \quad k_2 = T_1 \tag{8}$$

Finally, the temperature distribution on the wall thickness had the expression:

$$T(x) = \frac{T_2 - T_1}{\delta} x + T_1 \tag{9}$$

Using Fourier's law, the equation of the unit heat flow was obtained, in W/m^2:

$$q = \frac{\lambda}{\delta}(T_1 - T_2) \tag{10}$$

and the total thermal flow, Q_S (in W), would have the expression:

$$Q_S = \frac{\lambda}{\delta} A (T_1 - T_2) \tag{11}$$

where λ is the coefficient of thermal conductivity, and A is the finite area of the wall through which heat is transferred. The unit thermal flow is the amount of heat transferred in the unit of time through the unit of surface:

$$q = \frac{dQ_S}{dA} = \frac{d}{dA}\left(\frac{dQ}{dt}\right) = \frac{d^2 Q}{dA dt} \tag{12}$$

in which:

$$Q_S = \lim_{t \to 0} \left| \frac{\Delta Q}{\Delta t} \right| = \frac{dQ}{dt} \tag{13}$$

Q_S is the heat flow, and Q is the amount of heat (energy, J).

2. The influence of the insert concentration in the composite material on the unit heat flow and on the total heat flow

The thermal conductivity coefficient does not appear in the temperature distribution on the wall thickness (6), but the unitary thermal flow and the total thermal flow (10, 11) contain thermal conductivity as a factor and, therefore, these parameters depend on the thermal conductivity coefficient. In the experiments measuring the coefficient of thermal conductivity, it was found to change with the change of the concentration of insertion in the material.

For the composite material with clay matrix and corn cobs insert, the linear regression of the thermal conductivity coefficient in relation to the insert concentration was found as:

$$\lambda(c) = 0.003c + 0.487374 \tag{14}$$

For the composite material with a clay matrix and an insert made of chopped walnut shells, the linear regression of the coefficient of thermal conductivity, in relation to the insert concentration, was found in the form:

$$\lambda(c) = 0.0037997c + 0.456344 \tag{15}$$

Formulas (14) and (15) show that the value of the thermal conductivity coefficient is a function dependent on the concentration of the insert material in the composite. From formula (13), taking into account formulas (14) and (15), the formulas of the unitary heat flux on the walls of composite material with clay matrix and insert of corn husks (16) and for the composite material with matrix of clay and insert made of chopped walnut shells (17):

$$q(T1, T2, \delta, c) = \frac{\lambda(c)}{\delta}(T_1 - T_2) = \frac{0.003c + 0.487374}{\delta}(T_1 - T_2) \tag{16}$$

$$q(T1, T2, \delta, c) = \frac{\lambda(c)}{\delta}(T_1 - T_2) = \frac{0.0037997c + 0.456344}{\delta}(T_1 - T_2) \tag{17}$$

In the technique, two important concepts are used to determine the properties of walls, influenced by their geometry and physical structure (*https://www.isover.ro/parametrii-importanti-coeficientii-u-si-r*). The thermal insulation performance of a wall is represented by the thermal transfer coefficient U, expressed in W/(m^{2}K), or by the thermal resistance R, expressed in (m^{2}K)/W.

The formulas of these synthetic characteristics of the insulation capacity of the walls are given in the report:

$$U = \frac{\lambda}{\delta}, \quad R = \frac{\delta}{\lambda} \tag{18}$$

It can be seen, from relation (18), that the value of the thermal transfer coefficient U , and the thermal resistance R, depend directly, respectively inversely proportionally, on the thermal conductivity coefficient. Considering the empirically deduced formulas (14) and (15), it is found that these insulation characteristics of the studied composite materials can be tentatively programmed in the production process by choosing an insert and a suitable insert concentration.

3. A numerical solution of the heat transfer

For cases closer to reality (three-dimensional or two-dimensional simplifications, walls with complex shapes, with multiple joints, with a layered structure, etc.), the solution of equation (1) becomes more complicated. The solution exists, in general, for correctly set boundary conditions, but the solutions themselves can no longer be described by elementary, but by approximations (series of functions). There are often cases where equation (1) is solved by finite difference schemes or the finite element method.

Figure 5 shows a solution obtained by using the finite element method, using the MATLAB solution program for equations with partial derivatives. The solution of the MATLAB program works for planar domains (2D). The border portion of the box that contains the heat source was represented by a rectangle with a length of 280 mm (7 bricks with sides of 40 mm each) and a width equal to the height of one brick. A value of 30 mm was accepted as the approximate value of the height of the bricks (they are not formed at exactly the same value). On the inside of the box, the temperature is hypothetically constant (100ºC), and on the outside, also constant, at 21ºC (ambient temperature). A constant average temperature of 60ºC was entered on the ends of the row of bricks, the program not accepting the variable temperature with the coordinate on the width of the wall (40 mm). In these conditions, at the border, the temperature distribution on the thickness of the wall (30 mm) showed as in figure 5. To calculate the thermal flow and the amount of heat lost, the solution from figure 5 (the matrix of values corresponding to the considered finite elements) was taken and it was multiplied by the ratio between the coefficient of thermal conductivity and the thickness of the bricks (the height of the rectangle in figure 5), then by the area the considered wall.

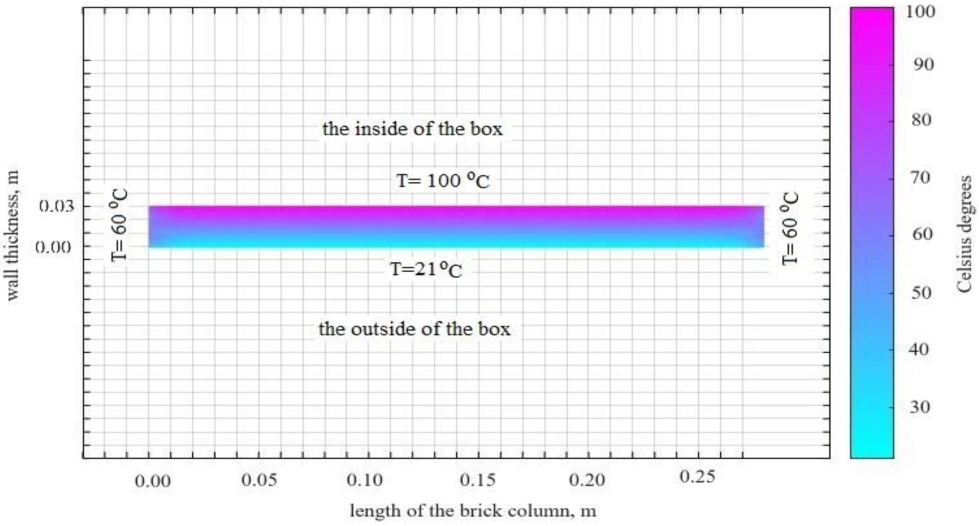


Fig. 5 - Temperature variation inside the wall (assembly) of seven bricks used to determine the coefficient of thermal conductivity (fig. 1c)

Mathematical models with finite elements for walls from MCMLIDA were also presented by *Florescu et al., (2019*). In the same work, the behavior of some stratified walls made of the same type of materials was also studied. This type of models can also be made in the case of composite materials with clay matrices and inserts of chopped corn cobs or walnut shells, experimentally researched and presented in the present article. Also, some authors use mathematical models to verify the empirical results and extend the results (*Abanto et al., 2020*).

Following the research, the following results were obtained:

- the value of the thermal transfer coefficient is directly proportional to the thermal conductivity;
- following the research carried out, a composite material with a suitable concentration of insertion can be chosen in order to obtain the value of the optimal heat transfer coefficient;
- figure 5 shows the temperature variation inside the wall in order to determine the thermal conductivity coefficient.

For the theoretical verification of the measurement method, figure 6 will show the temperature variation along the normal to the plane wall. This variation is simple, linear, and does not depend on the coefficient of thermal conductivity. Increasing the wall thickness linearly decreases (for this solution) the temperature at any point inside the wall.

Figure 7 shows graphically the dependence of the unitary flow of heat through a brick of composite material with a clay matrix with a thickness of 30 mm, in the version with an insert of shredded corn cobs and in the version with an insert of shredded walnut shells. It can be seen that for both composites, the increase in the concentration of the insert makes the brick material a better conductor of heat, therefore a weaker insulator.

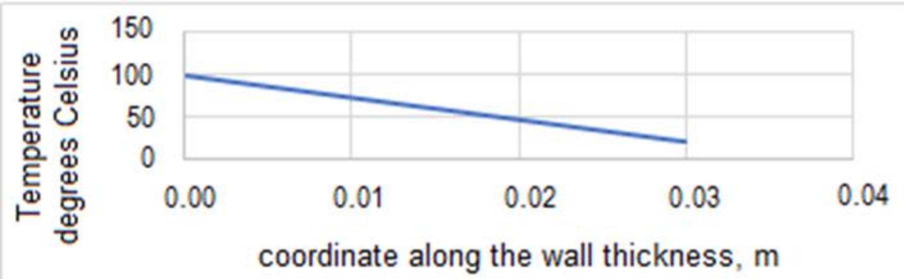


Fig. 6 - Theoretical variation of temperature on the thickness of the brick wall from MCMLIDA

A confirmation of the values of the coefficient of thermal conductivity is also noted in the relevant literature. *Lertwattanaruk et al.* found thermal conductivity coefficient values between 0.1 and 1.7 W/mK, for bricks with clay matrix and various insertion materials *(Lertwattanaruk et al., 2011, fig.1, page 55)*.

As can be seen from figure 2, the thermal conductivity coefficient λ , values found in the present experiments varied between 0.4 and 0.8 W/(mK).

Florescu et al, (2019), used for the mathematical models of the walls made of adobe bricks, values of the coefficient of thermal conductivity between 0.17 and 0.47 W/mK. *Abanto et al., (2017*), determined, for construction materials of the same type as those studied in the present research, values between 0.25 and 0.334 W/(mK) of the coefficient of thermal conductivity. For composite materials (mortar, clay and sand) *Calatan et al., (2020*), determined optimal recipes that maximize bending resistance and reach thermal conductivity coefficient values between 0.17 and 0.38 W/mK.

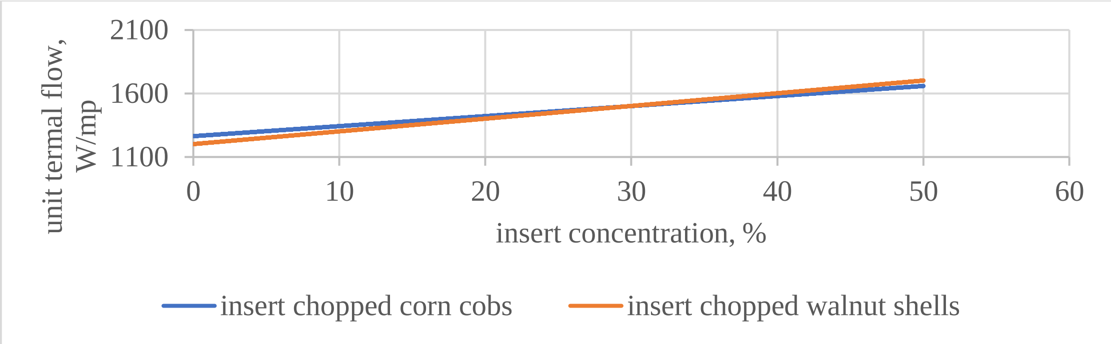


Fig. 7 - The variation of the unit heat flow through a MCMLIDA brick, with a thickness of 30 mm, in the version with an insert of chopped corn cobs and in the version with an insert made of chopped walnut shells

Figure 7 shows graphically the variation of the unitary heat flow depending on two variables: the concentration of the insert and the thickness of the bricks. The functions of two variables (13) and (14) were used for representation. Functions (13) and (14) have a theoretical-empirical character, because the general structure was deduced through the theory of heat transfer. The law of the dependence of the coefficient of thermal conductivity on the concentration of the insert, which appeared in the numerator of the fraction, was determined empirically with the help of statistical processing of the experimental data. It can be seen that the variation of the unit heat flux with the insertion concentration was linear, for both materials. The dependence of the unit thermal flow on the wall thickness was hyperbolic, so that the reduction of heat losses could be done preferentially, by changing the thickness of the brick and/or by choosing the appropriate concentration of the insert. Formulas (13) and (14) also show that the unit heat flow depended linearly on the temperature difference on the two faces (inside and outside) of the composite brick.

The variation of the unitary heat flow through adobe walls made of clay matrix with an insert of corn cobs shreds, depending on the concentration of the insert and the thickness of the wall, is represented graphically in figure 8. It can be seen that the variation with the thickness of the wall is much more intense than the dependence of the insertion concentration, non-linear, hyperbolic. The variation of the unitary heat flow with the concentration of the insert shows that with the increase of the concentration of the insert, the thermal conductivity of the wall increases, so the thermal insulation capacity decreases.

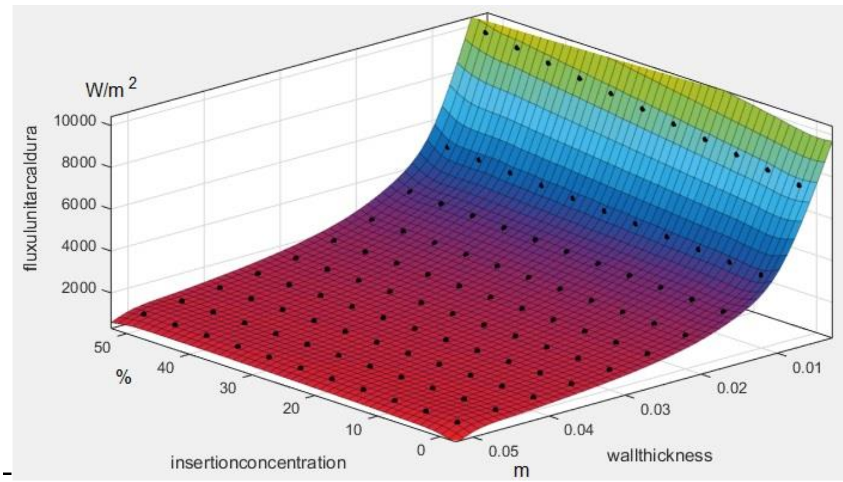


Fig. 8 - The variation of the unit heat flux with the insertion concentration and with the wall thickness

A last piece of information obtained later on the coefficient of thermal conductivity of composite materials with a clay matrix and an insert of shredded corn cobs, respectively chopped walnut shells, showed a strong dependence of the coefficient of thermal conductivity on the density of the final product and a significant one of product moisture (Table 1).

Also, there was a significant dependence on the compression force in the brick manufacturing process. This information is useful for future research regarding the structure of a formula of the thermal conductivity of the parameters of the manufacturing process, of the raw material and of the final product.

Table 1

Correlation values between the conductivity coefficient and the main parameters of the manufacturing process and of the finished material

Material	Pressing force, N	Initial humidity, %	Initial density, g/cm^3	Initial humidity, %	Initial density, g/cm^3	Humidity after 2 weeks, %	Density after 2 weeks, g/cm^3
Clay matrix with corn cobs	0.590	0.486	-0.340	0.522	-0.432	-0.398	-0.804
Clay matrix with walnut shells	0.747	0.660	-0.775	0.839	-0.743	0.718	-0.800

The dependence of the coefficient of thermal conductivity on the density of the raw material, of the product at the exit from manufacturing and after two weeks of storage, was, without exception, an inverse one. This is a serious indication of a formula for the coefficient of thermal conductivity in relation to the density of the material. This observation also confirms the fact that the density of the studied composites decreased with the increase of the insertion concentration, and the coefficient of thermal conductivity increased.

CONCLUSIONS

The usefulness of composite materials in construction is well known, especially if it is adobe. Their properties as thermal and sound insulators recommend them. Neither are the resistance to compression nor bending negligible, so there are many constructions made of these materials or that use them for infill walls, false walls or infill material.

Present research has found methods to obtain composite materials based on clay matrices and various insertion materials including agricultural waste, whose final properties can be programmed by choosing the characteristic parameters of the raw material and the technological process.

For now, the only control parameter of the properties of the obtained composite materials is the concentration of the insert material in the matrix. However, there are other important parameters in the process of obtaining composite materials, which have been insufficiently studied.

Some important conclusions relative to the thermal properties that are all related to the coefficient of thermal conductivity are stated below.

C1) The values of the coefficient of thermal conductivity obtained for the composite materials with clay matrix and chipping insert from corn cobs or walnut shells (0.4-0.8 W/(mK)) place them among the good thermal insulating materials;

C2) Within the limits of the insert concentrations in which the materials work (composite materials have cohesion and adhesion between matrix and insert 0-50% for the materials specified in conclusion C1), the coefficient of thermal conductivity increases with the volume of the insert concentration. Materials become weaker insulators (better heat conductors), as the concentration of insertion increases. In relation to this behavior, it should be specified that the bending and compressive strengths also decrease with the increase of the insertion concentration;

C3) The research continues and recent results show that the value of the coefficient of thermal conductivity depends inversely on the density of the material. With one exception, the coefficient of thermal conductivity is significantly related to the humidity of the material in all three specified technological stages. Also, there is a significant relationship between the coefficient of thermal conductivity and the pressing force in the brick mold.

C4) Conclusions C1-C3 also generate future research directions:

- the rigorous selection of the process parameters, of the raw material, control and regulation of the brick formation process and optimal storage parameters to obtain final products with improved qualities;
- re-evaluating the linear and non-linear regressions found in the preliminary experiments, in order to obtain possible optimal work regimes, including the qualities of the final product, but also energy and material consumption;
- the consideration of some alternative recipes for composite materials, with other agricultural or other waste, important suggestions being present in the literature;
- the research of complex solutions including complex, pre-stratified walls, in order to obtain adequate and optimal mechanical and thermal (in the future and acoustic) properties.

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