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COMPOSITE MATERIALS FOR ECO-SUSTAINABLE CONSTRUCTIONS

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Abstract

This work aims to research and promote construction products based on natural raw materials. The study and promotion of traditional materials can represent an answer to the problem of carbon emissions. More and more specialized studies prove the fact that new, modern constructions can alter both our lifestyle, compromising our physical, mental and emotional health. The conclusions of the studies do nothing but reinforce the idea of the fact that returning to traditional materials, their re-assimilation in current constructive techniques and solutions, represents the right solution both for the environment and for us as individuals. Research involves development and experimental research to check the characteristics and performance of products made from natural raw materials (clay, lime, straw, hemp, wood waste in the form of sawdust) and various additions and/or additives in the lowest possible percentages, by studying some recipes different compositions, in order to optimize them from both a mechanical and hydrothermal point of view, depending on the areas of intended use.

Key words*: adobe bricks, clay, sustainable development, traditional composites materials.*

INTRODUCTION

Since the dawn of industrialization, technological advances have advanced rapidly, outstripping the ability of the planet's natural resources to support them. In the context of global warming, habitat destruction, poverty and other increasingly urgent socio-environmental problems, it becomes obvious that it is necessary to invest in sustainable development practices. According to the Brundtland Commission, sustainable development is defined as "development that meets the needs of the present generation without neglecting the ability of future generations to meet their own needs".

The renowned environmental analyst Lester R. Brown who introduced the concept of Eco-economy, in the book published in 2001, Eco-Economy: Building an Economy for the Earth, draws attention to the tendency to exhaust natural resources of energy, raw materials and food, consumption of renewable resources at a rate higher than their regeneration capacity and physical damage and pollution of vital environmental factors: water, air, soil, which supports the need for innovation based on traditional - vernacular sources and the importance of developing the inhabited space in correlation with protecting the environment, Sustainable Development being seen as the "green solution" in the face of the ecological crisis determined by the intensive exploitation of natural resources that caused environmental degradation (Hegyi et al., 2021).

Innovative construction materials developed starting from the traditional - vernacular, find a significant place. Thus, the tendency is encouraged for traditional - vernacular architecture to no longer be seen as obsolete, outmoded, but to become a source of inspiration for innovation, all the more so as the benefits are known both in terms of the quality of constructions, the quality of the environment interior, low construction costs, at the same time with low maintenance costs and an appreciable contribution from the point of view of energy savings for maintaining thermal comfort in the living space. Last but not least, the advantages of this approach are also materialized at the level of the required resources - raw materials that are easily accessible and can be processed with human resources that do not require special qualifications, allowing both communities from economically developed countries and less developed countries from the point of view economically, an efficient exploitation of own resources benefiting from the knowledge fence that exists worldwide but which can be easily adapted to the local specifics by exploiting the so-called "store of wisdom" of the place.

We can have a healthy life through healthy building materials. According to worldwide studies, we spend between 60 and 90% of our lives indoors, breathing 11,500 litres of air per day, which implies the need to ensure a favourable indoor climate.

The quality of the indoor environment is essential when it comes to the role of buildings on our health. And this indicator is composed of the following elements: natural light, noise, thermal comfort and indoor air quality (Calatan et al., 2014).

Using clay as a building material has many advantages, such as: it balances air humidity, maintains heat, saves energy and reduces environmental pollution, is reusable, reduces costs for materials and transport, is suitable for self-built houses, absorbs polluting agents (Cazac et al., 2011).

An important property of clay is the absorption and release of moisture to a greater extent than other building materials, which influences the balance of the indoor climate. Based on studies (Baughman & Arens, 1996), it was concluded that the humidity level, from the point of view of a healthy environment in inhabited rooms, should be a minimum of 40% and a maximum of 60%. Measurements made over a period of 8 years in a newly built house in Germany, with all external and internal walls made of clay, showed that the indoor relative humidity was consistently 50% throughout the year, with fluctuations between 5% and 10%, which signifies the existence of healthy living conditions with balanced humidity both during summer and winter (Cazac et al., 2011).

In countries whose economy is predominantly agrarian, the use of natural agricultural waste in construction products can have important advantages compared to the use of traditional materials, including reduced environmental impact, lower energy demand, lower costs, availability at scale wide and good insulation properties (Yaashikaa et al., 2022; Rojas et al., 2019; Sanjay et al., 2018; Asdrubali et al., 2015).

The increase in production and consumption worldwide represents both a significant challenge for waste management and resource use and an opportunity as, by superior recovery of waste materials, industries can reduce waste disposal and related costs, reduce the consumption of conventional resources, thus participating in the development of the circular economy at a regional and global level.

It should also be stated that, not infrequently, the use of vegetable waste, as an addition or as a basic component, determines the obtaining of the new material/product at a lower production price compared to that of the traditional material/product, an important aspect in choosing the option to invest in manufacturing and bringing the innovative material/product to market.

At the national level, directions for the utilization of plant waste in constructions aim, on the one hand, at the superior utilization of some types of waste such as wood fibers or cereal waste, by obtaining innovative materials/products with thermal insulating characteristics, and on the on the other hand, obtaining bricks or masonry blocks, sound and thermal insulation boards, etc., and making load-bearing or non-load-bearing walls with these materials.

The use of hemp, apart from the general properties of plant fibers, is determined by its main specific characteristics, which include:

- The high growth rate of hemp crops, of 70-140 days depending on the degree of sunshine, are ecological, do not require herbicides, fertilizers or pesticides (Ahlberg et al., 2014);
- It consumes a significant amount of CO_2 during growth, with some studies indicating the existence of CO_2 consumption even after the plant has been put into operation. It is estimated that 1 m^2 of biocomposite based on hemp fibres, as a result of the carbonation of the lime in the composition, absorbs 14-35 kg of CO_2 over a lifetime of 100 years, actively participating in the reduction of greenhouse gases even during the period exploitation (Ezboziegbe & Mizi, 2013);

- It can be considered an inert material, the amount of CO_2 emitted during lime production being less than or at most equal to the amount of CO_2 consumed by plant growth (Ahlberg et al., 2014);
- Thermal and sound-insulating properties, permeability to air and water vapor and ability to regulate the humidity of the indoor environment, hemp dust - the woody, inner core of the stem, which remains after the fibers have been extracted for textile production - having various uses as building materials/products (Bruijn et al., 2008; Sinka & Sahmenko, 2013; Ahlberg et al., 2014).

Although straw is one of the oldest natural agricultural materials used in traditional Romanian constructions, nowadays they are gaining more and more ground in this field, but being used in modern forms in terms of straw processing technologies, installation techniques of construction, as structures, constructive systems, etc., resulting in straw bale houses - cheap, efficient and sustainable. The characteristics of straws include:

- Very low biodegradability compared to other agricultural residues, due to the high ratio of carbon vs. nitrogen (due to small amounts of nitrogen), especially in the case of rice and wheat straw (Bakker R. et al., 2013);
- Density between 81 - 106.3 kg/m^3 for oat and wheat straw bales and between 54.6 - 78.3 kg/m^3 for barley straw bales, the optimal density for wheat straw used in construction being 133 kg/m^3 and for rice straw, 123.6 kg/m^3 (McCabe, 1993; Watts et al., 1995);
- Permeability to vapours and liquid water, thus not needing the use of vapor barrier products. Also, they are a natural, ecological material, without negative effects on people's health.

Wood fibres (sawdust) present a series of general but also specific structural and chemical characteristics for this category of natural materials:

- From a chemical point of view, they are considered to be natural composites with a multilayered cellular structure, having as basic components cellulose - a natural polymer containing glucose units, hemicellulose - in turn a natural polymer made up of several polysaccharides and lignin - a mixture amorphous and heterogeneous of aromatic polymers and phenyl-propane polymers (Pacheco-Torgal & Jalali, 2010);
-The technical characteristics of this type of vegetable materials vary with the nature of the fibre but, in principle, they have a tensile strength comparable to that of synthetic fibres, although they have a reduced modulus of elasticity (Pacheco-Torgal & Jalali, 2010);
- The structure of plant waste is a basic element of them, generally showing interest.

In the study, recipes were tested based on clay and lime matrices with embedded plant materials: straw, hemp and sawdust. A comparative study of the physico-mechanical characteristics of the obtained mixtures was carried out.

MATERIALS AND METHODS

For the experimentally tested samples, the following stages of raw material preparation were kept: homogenization, formwork preparation, casting, drying and conditioning. The recipes are shown in Table 1.

Table 1. Mixture components

Components	Units	R1	R2	R3
Clay	kg	20	20	20
Lime	kg	20	20	20
Straw	kg	2	-	-
Hemp	kg	-	4	-
Sawdust	kg	-	-	4
Water	l	6	9	9

Ensuring the connection between the fibers of natural insulating material (cereal straw, hemp dust and sawdust) and stabilization against biological degradation, was also achieved by embedding them in solutions of clay, lime and water in quantities established according to the recipes, acting as a binder, of bactericide, bio-preservation, protection and moisture stabilization.

The mixture was made by hand or mechanized (Figure 1), a stage followed by the incorporation of the materials used to cast the thermal insulation boards, based on straw and hemp. The clay solution - slaked lime paste, was obtained by mixing and homogenizing some amount of softened clay and lime paste with water, until a mud-like consistency was obtained, on top of which the plant materials were added.

Figure 1. Preparation of the straw-based recipe mixture

The samples for the tests were cast in formwork systems made of chipboard, with dimensions necessary for the samples to determine the density, thermal conductivity and compression behaviour (Figures 2 and 3).

Figure 2. Filling the formwork with mixture

The behaviour of composite heat-insulating materials based on plant fibres in clay-lime matrix was studied by performing the following measurements:

- The determination of the density was carried out on samples dried at 80ºC by the gravimetric method. The exact dimensions of the samples were measured with an accuracy of 0.01 mm. The mass was determined using a balance with an accuracy of 0.1 g;
- The determination of thermal conductivity and thermal resistance was carried out on samples dried at 80ºC by the thermofluxmetric method;
- The determination of the compressive strength was achieved by applying a uniformly distributed and continuously increased load to the samples until failure.

The tests were carried out according to the references for tests specific to heat-insulating products, as well as those specific to masonry elements.

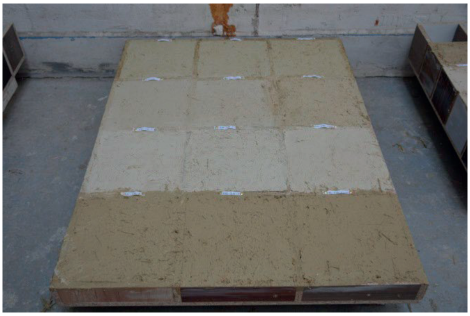

Figure 3. Appearance of cast samples

RESULTS AND DISCUSSIONS

The physico-mechanical characteristics of clay and lime-based mixtures with the addition of vegetable waste monitored in the experimental study are: apparent density, thermal conductivity and compressive strength.
The density was determined according to SR EN 1602:2013 - Thermally insulated products intended for use in buildings. Determination of apparent density.

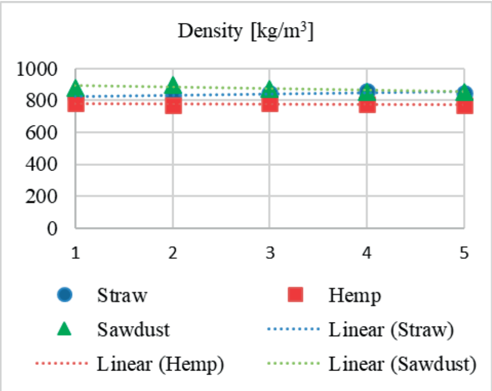

Figure 4. Density of hardened material

The samples were made in the form of cubes with dimensions of 150 x 150 x 150 mm, taken from heat-insulating composite material manufactured in the laboratory, based on lime, clay and the addition of local plant material. The obtained results are shown in Figure 4.

The apparent density (ρ_a) of the straw-added material varied between 820 kg/m^3 and 860 kg/m^3, with an average of 840.4 kg/m^3. The standard deviation from repeatability sr = 18.5 kg/m^3, representing 2.2% of the average value ρ_a.
The apparent density of the material with the addition of hemp recorded the lowest values, these being between 768 kg/m^3 and 781 kg/m^3, generating an average value of 775.4 kg/m^3. Standard deviation from repeatability sr = 5.6 kg/m^3, representing 0.7% of the average value ρ_a.
The highest average apparent density value – 871.8 kg/m3 was obtained for the mixture with the addition of sawdust, the individual values being in the range of 852 kg/m^3 to 899 kg/m^3. Standard deviation from repeatability sr = 19.2 kg/m^3, representing 2.2% of the average value ρ_a
The conductivity was determined according to SR EN 12667:2002 - Thermal performance of construction materials and products. Determination of thermal resistance by the guarded hot plate method and by the thermoflux meter method. Products with high and medium thermal resistance (Figure 5).

Figure 5. Testing thermal conductivity

Test pieces made in the form of plates with dimensions of 300 x 300 x 70 mm taken from heat-insulating composite material manufactured in the laboratory, based on lime, clay and addition of local plant material. The experimentally determined values are shown in Figure 6.

The average thermal conductivity λ_{10} of the composite with the addition of straw recorded the lowest value of the tested mixtures - 0.1480 W/mK, the standard deviation from repeatability sr = 0.0157 W/mK, representing 11.3% of the average value λ_{10}.

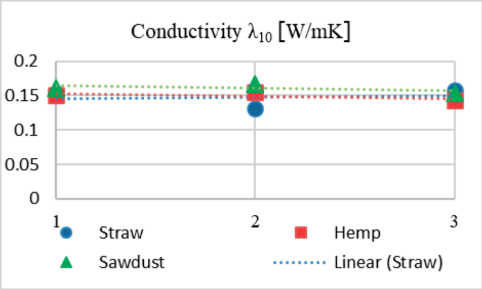

Figure 6. Thermal conductivity

The mixture with the addition of hemp marked a slightly higher average value of thermal conductivity λ_{10} – 0.1493 W/mK, standard deviation from repeatability sr = 0.0045 W/mK, representing 3.04% of the average value λ_{10}.
The highest average value of thermal conductivity was determined on the samples with sawdust addition - λ_{10} – 0.1609, the standard deviation from repeatability sr = 0.0043 W/mK, representing 2.7% of the average value λ_{10}.
The compressive strength was determined according to SR EN 772-1+A1:2016 - Test methods for masonry elements. Part 1: Determination of compressive strength. The samples were subjected to compression with a loading rate of 0.05 (N/mm^2)/s (Figure 8), the obtained values are reproduced in Figure 7.

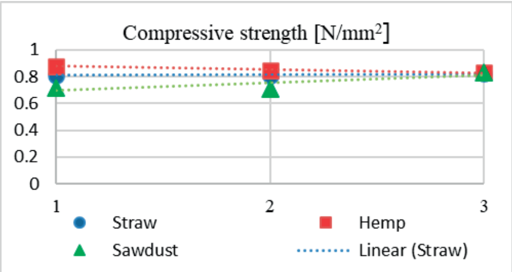

Figure 7. Compressive strength

The average value of the compressive strength (fb) of the material with straw addition determined experimentally in the laboratory is

0.81 N/mm^2, the standard deviation from repeatability sr = 0.004 N/mm^2, representing 0.5% of the average fb value. While the composite with hemp content recorded an average f_b value of 0.85 N/mm^2, the repeatability standard deviation sr = 0.25 N/mm^2, representing 2.9% of the average value f_b.
The compressive strength determined on the composite with the addition of sawdust marked an average value of 0.753 N/mm^2, the standard deviation from repeatability sr = 0.08 N/mm^2, representing 1.1% of the average value f_b.


Figure 8. Testing compressive strength

CONCLUSIONS

The use of natural agricultural waste in construction products is both a challenge for the construction materials industry. In this way, ecological materials can be produced, waste disposal costs can be reduced, the consumption of conventional resources reduced, participation in the development of the circular economy at regional and global level.
The utilization of natural agricultural waste in construction products presents a number of advantages compared to the use of traditional materials: reduced environmental impact, lower energy demand, low costs, wide availability and good insulation characteristics.
According to the results obtained in the experimental study, all three types of composites with the addition of vegetable waste: straw, hemp and sawdust presented similar values and a low degree of dispersion of the results.
Lower values of apparent densities specific to hemp-based materials are observed, followed by those based on sawdust, respectively straw.
The thermal conductivity maintains the same tendency of distribution of the results, the lowest values being recorded for materials based on hemp, compared to those from straw, respectively sawdust. Higher compressive strength values are observed for sawdust-based materials compared to straw and hemp.

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