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Green Plastering Mortars Based on Clay and Wheat Straw

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Abstract

This paper is part of a larger project which seeks to promote traditional, organic materials with similar features to classic building materials used in construction, but with a lower price and a positive impact on human health.
The aim of this study is to find a way to improve the mechanical characteristics of green plastering based on clay and wheat straw. Wheat straw is waste from agriculture, which most often are burnt in the fields, thus contributing to higher emissions of carbon dioxide. The study's objective is to achieve green mortars based on clay. To improve the mechanical characteristics, the influence of wheat straw as a reinforcing material was studied. It was studied how the geometric characteristics of wheat straw affect the properties of studied material.

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Keywords: ecology; straw; building materials; clay plaster.

1. Introduction

This paper is part of a larger project, which seeks to promote traditional and organic materials with similar characteristics to the conventional materials used in constructions, but with a lower price and a positive impact on human health. Environmentally friendly building materials have been used since ancient times, the first constructions being made from natural materials: stone, clay, straw, and sand. Along with industrialization, new materials started being used. These were produced on a large scale and contributed significantly to the increase of carbon dioxide emissions.

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The aim of this study is to find a way to improve the mechanical characteristics of clay-based plasters using wheat straw. Clay-based plasters are commonly used in ecological buildings, but lately, new demands have begun to emerge for classical buildings as well, especially for renovations. Since classical plasters contain substances that create allergies, people tend to choose organic clay-based plasters, which allow the walls to breathe and which represent, at the same time, a significant thermal mass.

Wheat straw is treated as waste in agriculture and it is most of the time burnt in the fields, thus contributing to higher emissions of carbon dioxide. This phenomenon is repeated annually and has become a concern for the authorities in charge. In order to use wheat straw as fertilizer, they should be chopped, which implies a mechanized process with high energy consumption and carbon dioxide emissions.[1]

Recycling wheat straw represents a continuous challenge for engineering, the focus being on materials made from wheat straw or on those containing wheat straw.

One of the great problems mankind is facing is carbon dioxide emissions. All governments encourage the construction of housing with a carbon footprint which tends towards zero. If one takes into account the materials classical buildings are made from and analyzes both the amount of carbon dioxide released into the atmosphere during their production process, and the carbon dioxide emissions during transportation, it can be noted that the total carbon dioxide emission is much greater than the amount of carbon dioxide materials can retain over their lifetime.[2]

Constructions with negative carbon footprint can be made using environmentally friendly, natural materials, such as wheat straw, wood, hemp. Since these raw materials grow directly from the ground and do not require a particular processing, like any other plant, they have the ability to retain carbon dioxide and to release oxygen, thus having a negative carbon dioxide footprint.

It is well known that after water and sand, cement is the most used material worldwide, making it the largest polluter in the world. This is why this paper aims to provide the characteristics of clay-based plasters and ways to improve the mechanical strengths by adding wheat straw.[3]

2. Materials and Methods

2.1. Materials

The suggested innovative material is represented by a composite material made of clay and wheat straw. In order to improve the mechanical characteristics, the influence of wheat straw as a reinforcing material needs to be studied. The focus was on the way in which the geometrical characteristics of wheat straw influence the properties of the analyzed material.

There were made six recipes of mortars, two recipes with simple clay and four recipes with clay and wheat straw. Two types of clays were used: commercialized clay and clay extracted from the region of Năsăud. Two types of wheat straw from the August 2013 crop were also used: straw with the length of (1 -2) cm and chopped straw with dimensions (from 0.1 to 0.2) cm.

Clay is a fine-grained sedimentary rock (<2 μm) consisting of a mixture of silica and of fragments of quartz, mica, etc. Clay minerals are formed by the long chemical action of carbonic acid and other natural solvents. Clay prevents the proliferation of microbes or of pathogenic bacteria. Knowing its antiseptic action, Egyptians used clay for mummification.

In order to study the characteristics of clay mortar, the used plaster was made from commercialized ProCrea clay and clay extracted from the ground.

Cereals represent the phytotechnical group of plants with the highest area of distribution in all growing areas of the globe, including Romania as well.

In Table 1 below we can see the chemical composition of the wheat straw:

Table 1. Chemical composition of the wheat straw

The main components	Percentage %
Crude proteins	2-4
Crude fats	1-2
Non-nitrate extractables	33-40
Cellulose	30-40
Ash	3-12

The ash present in the wheat straw is composed of 70-80% silica and 10-13% potassium. [4]

2.2. The Preparation of Composites

A composite material consists of matrix and reinforcement material (reinforcing filler)[5]. In this paper, we propose studying the 6 recipes of clay mortar, 4 of which contain wheat straw. The properties of the straw depend on its shape and influence in turn the properties of the composite material in a determinant way. Straw of two dimensions was used: straw with the dimensions of (1-2) cm and chopped straw of (0.1 to 0.2) cm.

The entire process started from personal recipes to which wheat straw was added. The determination of the physical-mechanical characteristics was performed according to the standards from the Construction Materials Laboratory of the Faculty of Construction.

The 6 mortars were prepared according to the recipes shown in the In Table 1 below:

Table 2. Clay Mortar Recipes

Recipe	ProCrea Clay [%]	Clay N [%]	Water [%]	Hydraulic bad [%]	Straw 1-2cm [%]	Chopped straw [%]
A1	64		16			
A2	70		25		5	
A4		21	16	63		
A5		17	26	52	5	
A7	70		25			5
A9		17	26	52		5

Prisms of 4x4x16 cm dimensions were poured from the recipes thus prepared. Dried12-month-old wheat straw, kept in low humidity conditions, was used with the above specified dimensions.

2.3. Methods

The mechanical properties of the standard mortar were determined according to SR EN 196. On the mortars thus obtained, flexural tensile strength and compressive strength were determined. First, the samples were tested in tension through bending. Then, compression testing was performed on the resulted halves. The samples were prepared and stored according to SR EN196. The determinations of the mechanical resistances were carried out after 28 and 90 days since their preparation.

2.3.1. Traditional Methods

The Determination of Bulk Density

The determination was carried out at 28 and 90 days. Prisms were weighed, L, l and h prism dimensions were measured, and then apparent volume and bulk density were calculated. Table 3 indicates the common values:

Table 3. Bulk Density

Recipe	A1	A2	A4	A5	A7	A9
$\rho_{a\ med\ 28\ days}$ [g/cm^3]	1.766	1.210	1.820	1.140	1.266	1.134
$\rho_{a\ med\ 90\ days}$ [g/cm^3]	1.753	1.190	1.770	1.090	1.251	1.129

The Determination of Flexural Tensile Strength

It was achieved with the device for determining the flexural tensile strength on three prisms from each recipe with 40x40x160 mm dimensions, in the Construction Materials Laboratory of the Faculty of Construction. Shockless loading was applied at uniform speed in the range of 10 N / s and 50 N / s so that the rupture occurs in a period of 30 seconds to 90 seconds. The maximum applied load is recorded in Newtons. Table 4 below shows the shows the obtained results:

Table 4. Values of Flexural Tensile Strength

Recipe	A1	A2	A4	A5	A7	A9
$R_{ti\ med\ 28\ days}$ [N/mm^2]	0.816	0.510	0.980	0.600	0.450	0.490
$R_{ti\ med\ 90\ days}$ [N/mm^2]	1.155	0.550	1.040	0.600	0.490	0.510

In the Fig. 1 below one can see a prism tested in bending and its breaking way.

Fig. 1. Testing Flexural Tensile Strength

The Determination of Compressive Strength

The determination of resistance to compression is performed on the remains of the prism resulted after the flexural tensile test, by using hydraulic press.

Fig. 2. Compression Test for A1 Mortar

Prisms will always be tested perpendicularly to the pouring direction, resistances being smaller in this direction due to the possibility of segregation of mortars. A progressively growing shockless loading will be applied with an increasing load rate of about 50 N / s up to 500 N / s so that a rupture occurs within an interval between 30 seconds and 90 seconds. A maximum applied load is registered in Newtons.

The obtained results are shown in the table below:

Table 5. Values of Compressive Strength

Recipe	A1	A2	A4	A5	A7	A9
$R_{c\ med\ 28\ days}$ [N/mm^2]	2.010	0.640	2.470	0.670	0.500	0.440
$R_{c\ med\ 90\ days}$ [N/mm^2]	2.576	0.770	2.520	0.710	0.510	0.490

2.3.2. Modern Methods of Investigation Applied to Plaster Mortars Made of Clay with Added Straw

Nuclear Magnetic Resonance Measurements

NMR measurements of the samples were performed using a 20 mq minispec Bruker working at 19.7 MHz. The temperature of the samples was measured during the measurements, and it was 20.3° C. One-dimensional pulse sequences of type CPMG (Carr-Prucell-Meiboom-Grill) were used in order to obtain distributions of NMR relaxation times and bi-dimensional of type T2-T2 and T1-T1 to obtain some molecular exchange folders in porous and correlation environments. [6]

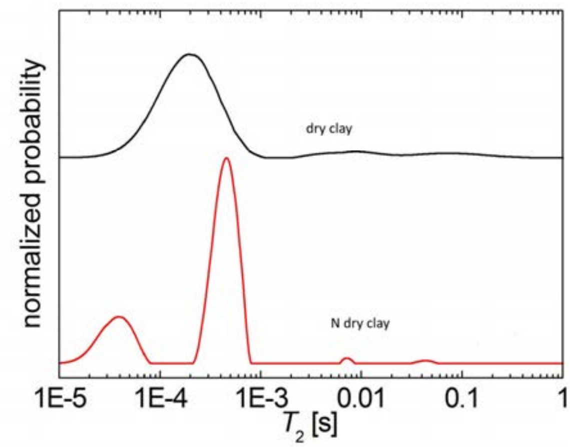

Fig. 3. Normalized probability of two different types of dry clay

The Fig. 3 compares commercialized clay rated as “dry clay” and N clay extracted from the ground. In the case of the commercialized clay, approximately 3 drippings can be seen, a main one at a T2 value of 0.2 ms and two drippings at higher T2 values, of 10 ms and respectively 80 ms, which shows that there is hydrogen bound to rigid components. For extracted N clay four drippings can be observed, two smaller at T2 values of about 70 ms and 50 ms. Similarly, it can be noticed that the hydrogen tanks are linked to the rigid components.[7]

The Figure 4 below shows the distributions obtained by inverse Laplace transformation of the drops for the simple commercialized mortar and the one with added straw after 1 day and 28 days.

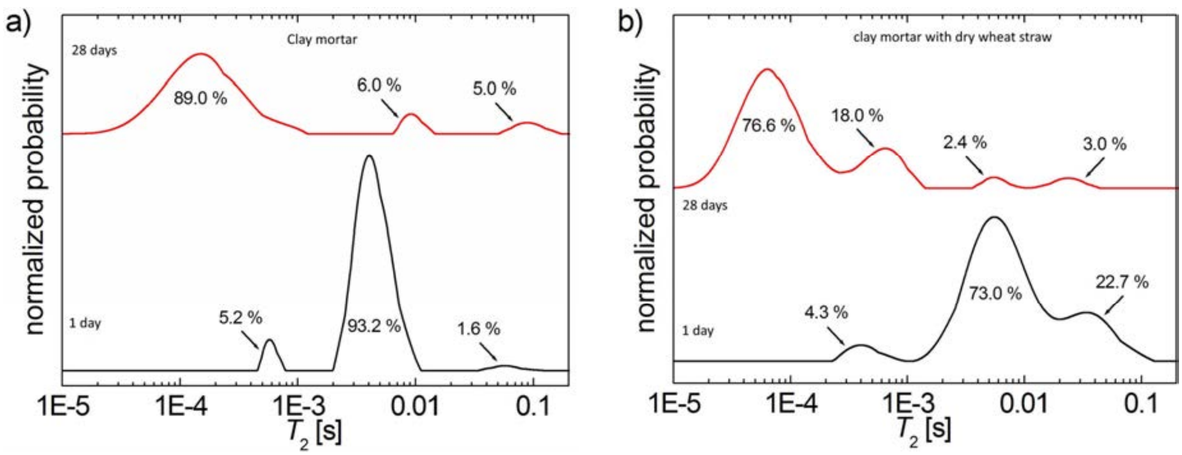

Fig. 4. a) Normalized probability of clay mortars at 1 and 28 days; b) Normalized probability of clay mortars with dry wheat straw at 1 and 28 days

As a general characteristic, one can notice that for both types of mortar – simple commercialized mortar and commercialized straw mortar – three drippings are obtained. For commercialized clay mortar at 28 days the hydrogen tanks migrate to more rigid parts. Thus, we can say that the existing water in mortar after 28 days is water of hydration that clung to the rigid components of the mortar. For clay mortar at 1 day, a water content of 93.2% is found in a central dripping, representing practically the semi-rigid clay paste. In Figure 4b) one can notice that straw introduces the biggest inhomogeneities, meaning it radically changes the local environment from the clay. After one day it can be seen that the distributions are very broad, and after 28 days, 4 such types of distributions make their appearance. Again most of the water is located in the reservoirs which may be associated with the rigid components, i.e. approx. 76.6% of the water is water of hydration: about 18% of the water may be found in small pores, 2.4% in average pores and 3% in large pores.

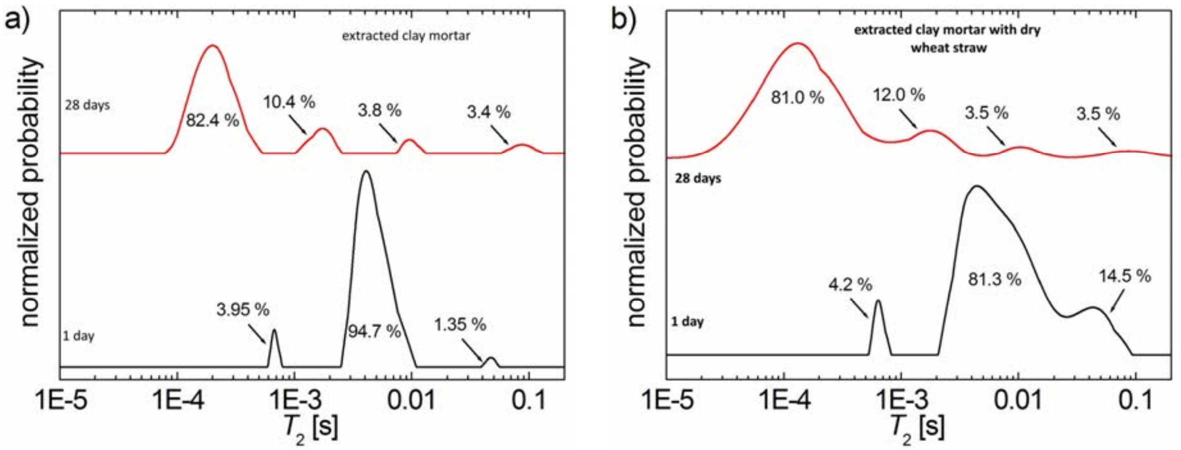

Fig. 5. a) Normalized probability of extracted clay mortars at 1 and 28 days; b) Normalized probability of extracted clay mortars with dry straw at 1 and 28 days

The figure above shows the distributions obtained by inverse Laplace transformation of the drops for the extracted clay mortar, simple and with added straw after 1 day and after 28 days.
Like in the case of the commercialized mortar, the biggest effect belongs to the dry straw, whose distribution of T2 is much broader, meaning it alters the local environment and the growth of inhomogeneities. After 28 days the differences are greater and more visible. In the case of the straw mortar there is a distribution with four drippings that could be associated with large, medium and small pores. It may be noticed that the straws contribute to reducing pores in the mortar. This can be observed in the movement of the two drippings corresponding to the medium and large pores with values of about 90 ms for the straw-less clay mortar and to values of 30 ms for straw-clay mortar.

3. Results and Discussions

The result of the determinations shows that straw has a significant influence on clay mortars. In both cases, straw changed their structure, having an effect of modification of the local environment and of growth of inhomogeneities.

It has been found that the results obtained after 90 days for all the tested recipes were better, the resistance values being higher. For straw clay recipes the mechanical strengths are noticeably lower than for the clay mortar with no added straw, a fact supported by the MRI investigation results.

After completing this first stage, it was found that the mechanical strengths have not increased when dry wheat straw was added. It appears that wheat straw have absorbed some of the water necessary to hydration. This is the reason why a next step is suggested, in which wheat straw is saturated before it is introduced into the clay mortar.

4. Conclusions

The inhomogeneity given by placing straw in mortars, observed in MRI tests, supports the results for the mechanical tests.

It was found that, by using wheat straw, there are possibilities of making new building materials with characteristics similar to conventional materials, but which are organic, natural.

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