
ECOLOGICAL EARTH-BASED MORTARS REINFORCED WITH WOOL FIBERS

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ABSTRACT

The earthen houses building heritage must be preserved and rehabilitated in order to cope with current use without endangering the security of the inhabitants and to ensure living conditions at the level of new housing standards. Within a research program carried out at NIRD "URBAN-INCERC", Timișoara branch, studies and laboratory tests were carried out on compositions of earth-like clay with/without reinforcement elements made of natural fibers (sheep's wool) in order to achieve plaster mortars with superior mechanical characteristics.

Keywords: mortar, clay, wool, stabilized earth

REZUMAT

Patrimoniul construit, alcătuit din case cu structura din pământ trebuie păstrat și reabilitat cu scopul de a face față utilizării fără să pună în pericol securitatea locuitorilor și să asigure condiții de trai la nivelul noilor standarde de locuire. În cadrul unui program de cercetare derulat în INCED "URBAN-INCERC", Sucursala Timișoara, s-au realizat studii și încercări de laborator asupra compozițiilor pe bază de pământ de tip argilă cu/fără elemente de armare din fibre naturale (lână de oaie) în vederea realizării de mortare de tencuială cu caracteristici mecanice superioare.

Cuvinte cheie: mortar, argilă, lână, pământ stabilizat

1. INTRODUCTION

The earthen houses building heritage is found all over the world, in all areas - arid, tropical and temperate, totaling about 15% of the protected UNESCO protected area. These constructions are decades old and in various stages of degradation (Stazi *et al.*, 2016).

With the emergence of materials such as burnt bricks, concrete, metal and modern building techniques, these structural systems have been completely ignored, with no skilled labor for building and repairing them.

The legislative framework in force in the European Union regulating construction activity does not provide for structural systems in the earth but only for brick blocks (Jimenez Delgado and Canas Guerrero, 2007).

Worldwide, in a few countries, norms and standards that regulate structural systems in the earth have been maintained either by the "rammed earth" or the "adobe" method.

The steady increase in the earth globe population, estimated at 9.6 billion inhabitants in 2050 according to the UN report 2013, brings with it an increase in the number of

living and working areas, which is causing serious environmental problems due to, on the one hand, increasing the amount of natural resources used and, on the other hand, increasing the pollution of the environment due to the industrial activities for their processing and commissioning as well as an increase in the amount of energy for heating and cooling the constructions during use.

At the end of the service life, modern buildings made of brick, concrete or metal generate significant amounts of waste, which in a small part can be recyclable, requiring laborious processes to disintegrate them, consuming energy and fossil fuels. Even constructions using wood are advisable to be used with moderation in view of the problems generated by the massive forest explosions (Melia *et al.*, 2014).

The use of unprocessed land is a sustainable alternative to burnt brick blocks and concrete elements for low-load building, bringing important benefits due to low energy consumption, thermal mass and natural

moisture regulation regardless of the building technique (Galan-Marin, 2010).

Taking into account the issues listed above, numerous researches have as object the construction of sustainable, local materials, which require low energy consumption for extraction, transportation, processing and commissioning and provide during the exploitation period conditions of habitation with low energy consumption, no harmful substances and no other health effects due to low ventilation.

In order to mitigate the disadvantage of the earth structures at the action of rain water, it is necessary to protect the external walls of the earth, irrespective of the method of their realization, by applying mortars with the best characteristics in terms of adhesion to wall, of the cracking process during the drying process, durability over time and eventually heat-insulating properties.

2. EARTH STABILIZATION

Even if the additions in the soil mixture of vegetal or animal origin fibers were used long time ago, for the purpose of improving the characteristics and durability of the earth, the quantification of their contribution was made in the recent researches with the help of modern equipments for the determination of different resistance characteristics.

Depending on the flora and fauna specific to the climatic zone where the constructions were made, to improve the durability (resistance to water action) and mechanical performance (resistance to compression and adhesion) were used (Laborel-Preneron *et al.*, 2016):

- natural fibers: grain straw, wood fiber, hemp, jute, flax, tobacco, cotton, palm, manioc, banana, coconut, seaweed;
- animal fibers: sheep, goat, horse.

The use of sheep wool for 25% reinforcement of clay compositions resulted in an increase in flexural strength of 30% tested specimens (Galan-Marin, 2010) and the propagation of cracks during the drying of the clay was limited due to the presence of fibers by increasing the adhesion between clay and

fibers. The use of longer fibers (from 1 cm to 3 cm) caused an increase in resistance due to the anchoring effect of the fibers (Aymerich *et al.*, 2012).

Earth mortars have in composition clay, dust and sand. Clay particles have the ability to bind larger grain particles but cause cracking of the mixture.

Adding sand to the composition will determine a decrease of shrinkage and increase the mechanical strength of the mortar (Hamard *et al.*, 2013).

The vulnerability of mortars to water has been diminished by incorporating oils or fats as biopolymers or lime into the composition of the mixture to reduce the cracking process.

In the case of constructions located in areas with excessive humidity and frequently exposed to rainfall it is necessary to apply non-cracked mortars that do not allow the water to penetrate the walls, which would subsequently deteriorate them (Eires *et al.*, 2017).

The addition of stabilizers or biopolymers causes electrostatic change of the clay particles which can lead to dispersion or flocculation. The dispersion effect reduces the water content to obtain a higher viscosity (Hamer and Hamer, 1975) and the flocculation effect approaches the clay particles. Biopolymers may first cause dispersal and subsequent attraction of clay particles, resulting in a better connection between them and thus preventing the passage of water (Fontaine *et al.*, 2009).

Biopolymers such as fats, oils, wax, milk or eggs are different, but have amphiphilic molecules that simultaneously promote a hydrophobic (water-repellent) effect and hydrophilic (water absorption) effect.

The hydrophilic part is the absorption by the clay particles and the hydrophobic part is located on the surface of the clay particle in contact with the air, creating a film that prevents the flow of water. This results in a water resistance effect and at the same time water absorption is controlled on the surface allowing the exchange of water vapor with the environment (Eires *et al.*, 2017). Biopolymers are generally incorporated with lime during hydration of lime.

There are 2 different stages of preparation:

- adding the oil or fat to the lime and an adequate amount of water for hydration and then adding the soil (Eires, 2012; Cechova, 2009);
- simultaneous mixing of the soil with oil or fat, lime and the necessary quantity of water for lime hydration (Heathcote, 2006; Malgalha *et al.*, 2006).

Cechova E. (2009) mentions in a lime mortar study that oil has been added that "the SEM observation suggests that there is a thin oil film evenly spread in mortars structure, covering the grains of binder".

3. EXPERIMENTAL WORK

3.1. The materials

Under a research program carried out in the Timisoara branch, laboratory studies and laboratory tests have been carried out on compositions of earth like clay with/without reinforcement elements of natural fibers (sheep's wool) in order to achieve plaster mortars with superior mechanical characteristics.

The material for making the earth specimens has a large proportion of clay particles. The fine clay particles present in the earth's composition cause the aggregation of larger dimensions such as sand and plasticity to be bonded over the wet application period. But during the drying process, with the elimination of the water in the composition, a network of cracks develops. These cracks, in addition to the unsightly effect, may lead to detachment from the substrate and to the possibility of water infiltration. In order to improve the mechanical properties of the mortars made from clay, namely to prevent the occurrence and development of cracks and to increase the adhesion to the support layer, wool fibers were added in the composition of the mortar.

Following the bibliographic studies in the literature (Jimenez Delgado and Canas Guerrero, 2006, 2007; Hamard *et al.*, 2016; Rama Subbarao and Purna Chandra Rao, 2014; Niculescu Enache, 2013) a composition has been established, consisting of

granulometric fractions with a certain percentage.

The soil used for mortar compositions has the following characteristics:

- humidity (W) - 21.20%
- kneading limit (Wp): 19.00%
- plasticity Limit (WL): 45.00%
- plasticity Index (IP): 26,00
- consistency index (IC): 0.92
- volumetric weight (c): 19,82 kN / m³
- deformation mode (M2-3): 9950 kPa
- inner friction angle (ϕ_u): 17,70 °
- cohesion (Cu): 99.00 kPa

3.2. Methods

The soil was processed by drying at 105°C and sieved in fractions of particle size with diameters between 0 and 2 mm. The weight of wool fibers was 1.5% of the mass of the blend. Sunflower oil was added to the mixture.

Percentage of the soil used for composition is as follows:

- Particle diameter <50 μm - 7%;
- Particle diameter 50 μm ÷ 63 μm - 10%;
- Particle diameter 63 μm ÷ 100 μm - 10%;
- Particle diameter 100 μm ÷ 200 μm - 10%;
- Particle diameter 200 μm ÷ 250 μm - 10%;
- Particle diameter 250 μm ÷ 500 μm - 10%;

The percentage of standardized sand used for composition is as follows:

- Particle diameter <2 mm - 43%;

The **samples of mortars** without and with wool were achieved according to the following steps:

- sieving the soil in fractions, Fig. 1;
- preparing a quantity of wool fibers representing 1.5% of the total weight of the earth (clay and sand), Figs. 2 and 3;
- mixing the fibers in the soil composition;
- placing the mixture in the pattern with dimensions of 40x40x160mm;
- placing the composition on the surface of earth walls, Fig. 4.

The composition of clay, silt, sand without/with wool was applied to samples of earth wall (to determine adhesion to the support layer) and was molded in a 40 x 40 x 160 mm form.

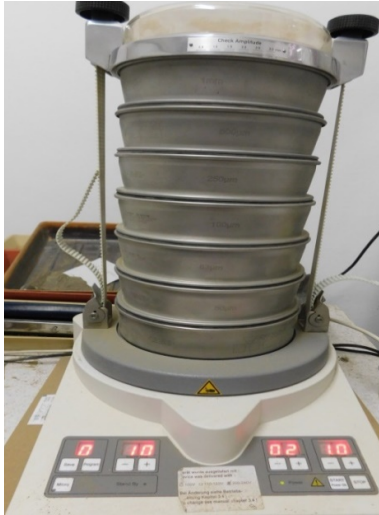


Fig. 1. Sieving earth through vibration



Fig. 2. Aspect of wool fibers



Fig. 3. Aspect of wool fibers in composition



Fig. 4. Placing the composition on the earth wall

4. RESULTS AND DISCUSSIONS

4.1. Axial contraction on prismatic samples

$$\varepsilon = \frac{L_o - L_i}{L_o} \times 100 \quad (1)$$

L_i - prism length after 28 days [mm];

L_o - initial length of prism with nominal dimensions of 40x40x160mm [mm].

Table 1. Axial contraction results

Mortar	L_o [mm]	L_i [mm]	ε (%)	Average	Decrease [%]
Mortar without wool	160	150.34	6,04	6,06	
	160	149.94	6,29		
	160	150,62	5,86		
Mortar with wool	160	156,45	2,22	2,06	- 66,05
	160	156,3	2,31		
	160	157,37	1,64		

The value of the axial contraction calculated after 28 days of achievement decreased by 66%. In Fig. 5 and Fig. 6 is the aspect of the specimens after drying period.

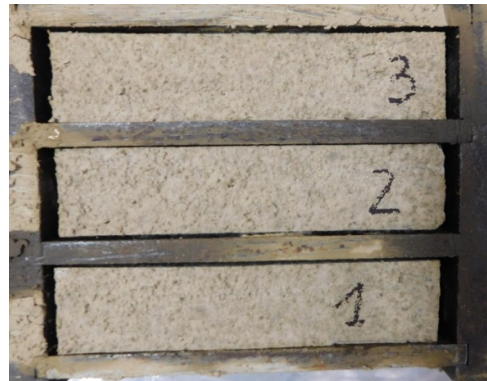


Fig. 5. Aspect of specimens of mortar without wool

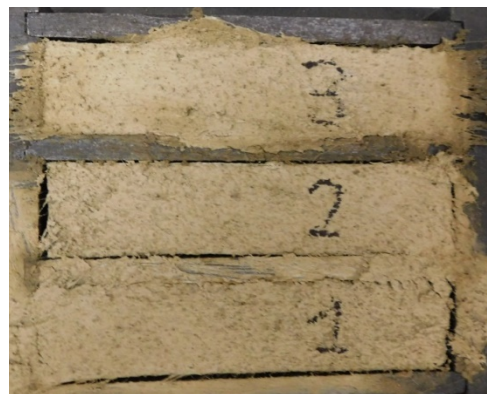


Fig. 6. Aspect of specimens of mortar with wool

4.2. Apparent density of the hardened mortar

$$V = L \times l_1 \times l_2 \quad (2)$$

$$\rho = \frac{m_{dry}}{V} \times 100 \quad (3)$$

L, l_1, l_2 - prism length on the 3 sides [mm]

V - volume of the dry sample [mm³];

m_{dry} - mass of the dry sample [kg].

The apparent density of mortar with wool decrease with 4.4%, from 1771 kg/m³ to 1693 kg/m³.

4.3. Bending strength

$$R_{ti} = \frac{3Pl}{2b^3} \quad (4)$$

P - the breaking force at bending [N];

l - support spacing (mm), $l = 100$ mm;

b - the square of the prism section [mm].

4.4. Compression strength

$$R_c = \frac{F}{A} \quad (5)$$

F - compressive breaking force (N);

A - area of the square section of the loading device [mm²].

Table 2. Bending and compression strength results

	Mortar without wool		Mortar with wool	
	R _{ti}	R _c	R _{ti}	R _c
	[N/mm ²]		[N/mm ²]	
1	0,80	1,97	0,85	3,78
2	0,76	1,59	0,87	3,75
3	0,72	1,56	0,89	3,13
Average	0,76	1,71	0,87	3,56
Increasing [%]			+14.36	+108

4.5. Adhesion strength

$$f_u = \frac{F_u}{A} \quad (6)$$

F - the force recorded at the time of removal from the support layer [kN];

A - the detached surface (the surface of the metal plate) [mm²].

The adhesion strength to the support layer increased with 87.69% from 0.45 N/mm² to 0.85 N/mm² (Figs. 9 and 10).



Fig. 7. Aspect of samples of mortar without wool after bending and compression

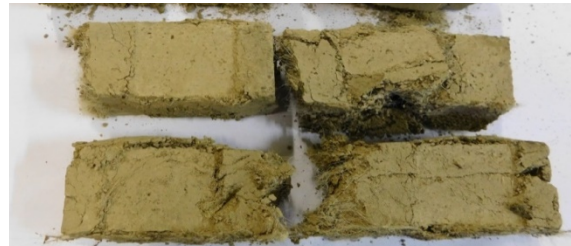


Fig. 8. Aspect of samples of mortar with wool after bending and compression



Fig. 9. Aspect of samples of mortar without wool



Fig. 10. Aspect of samples of mortar with wool

5. CONCLUSIONS

The advantage of using earth mortars is that unlike lime and cement mortars, the earth has the same mechanical properties and permeability of water vapor as the walls of the earth, which results in very good co-operation.

The use of these materials makes it possible to produce ecological houses from local, natural materials and with superior mechanical properties.

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