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STUDIES REGARDING THE USE OF POURED EARTH IN BUILDINGS

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Abstract

This study explores poured earth construction as an environmentally friendly alternative to conventional cement-based materials. Soil materials, mirroring natural concrete with grains bonded by clay particles, presents environmental benefits, including recyclability, low environmental impact, and effective hygrothermal regulation. The decline in traditional earth construction is associated with industrialization, prioritizing efficiency over traditional methods The technique involves pouring a mixture of local earth, sand, gravels, and a modest quantity of either Portland cement or additives as alternatives into formworks to fabricate load-bearing and non-loadbearing elements. Despite its potential as a sustainable option, challenges such as shrinkage control and durability persist. Poured earth construction can be a substitute for cement-based materials. Ongoing research and practical applications illustrate feasibility, but further advancements are necessary to enhance productivity and mitigate environmental impact, with additives for stabilization emerging as a prospective way for future development.

Key words*: clay, formwork, load bearing, poured earth.*

INTRODUCTION

In the pursuit of sustainable development solutions, the use of natural, recyclable, and low-energy-consumption materials, along with building systems and technologies that promote safety, flexibility, and energy efficiency, is becoming increasingly relevant. The thermal performances of buildings, which directly impact energy efficiency, have significant economic, social, and environmental implications. Consequently, the energy consumed throughout a building's lifespan emerges as a key element in the construction sector, underlining the necessity of adopting sustainable and energy-efficient construction practices.

However, the current approach of standards primarily focuses on the objective of energy efficiency, which limits the definition of sustainability and overlooks the specificity of place and relevant cultural and regional aspects. In this context, there is a need to pay greater attention to the social and cultural components of local specificity to develop solutions that enhance the sense of belonging and encourage the formation of communities with common interests. This can be achieved by leveraging the specific knowledge of the local community in developing sustainable architectural solutions, aiming to strike a balance between energy efficiency and cultural and regional appropriateness.

Vernacular building techniques, inspired by local traditions, represent adaptive ways to the specific conditions of the environment (Özen et al., 2012; Alrashed et al., 2017; Moscoso-García & Quesada-Molina, 2023). Therefore, traditional buildings made with soil materials are capable of meeting a wide range of physical and spiritual needs, seamlessly integrated into the context of the communities in which they are located (Salgin et al., 2017).

Despite the interest shown by the scientific community, the practical use of these materials remains limited. In order to stimulate the interest and usage of soil-based materials in construction (Morel et al., 2021) conducted a study to identify and analyse the latent barriers hindering the adoption of these types of constructions on a large scale, namely: technical, organizational, political and socio-economic barriers. The scientific community is concentrating on the technical aspect in evaluating the performance of soil-based materials with different additives or waste products (Limami et al., 2020; Makrygiannis & Tsetsekou, 2022; Wolf et al., 2022), especially those containing complex compositions like cob, rammed and poured earth walls with large elements such as gravels, stones, and synthetic or natural fibres (Ojo et al., 2020; Koutous & Hilali, 2021; Sabbà et al. 2021; El Bourki et al., 2023) testing on representative elementary volumes presents challenges (Pinel et al., 2021). Additionally, further investigation is warranted into the actual effects of earth-based materials on thermal behaviour (Mansour et al., 2016; Dao et al., 2018; El Wardi et al., 2022) and indoor air quality (Gomes & Miranda, 2022). Research gaps exist in understanding and controlling the drying kinetics of these walls and their consequential impact on mechanical properties (such as creep and strength) and durability (including resistance to freezing-thawing cycles and fire). Furthermore, there is a need to identify conditions leading to durability issues and develop tools to manage them effectively. Additionally, assessing inhabitant comfort (Ben-Alon & Rempel, 2023) and the influence of earthen walls on it, remains an underexplored technical area deserving future exploration.

The organizational barrier consists of few regulations internationally and especially the lack of standards in Romania to allow the use of earth/clay in the design or execution of constructions. A short review of publications dealing with the construction of rammed or poured earth houses in seismically active zones reveals that most of these documents are designed as instructional publications providing construction specifications to be followed. However, only two of these, namely the work of Arya A.S. (Arya et al., 2014) and the NZS 4297 standard, include formulas for seismic design. Other publications refer to other works to obtain more details on seismic design, such as the NZS 4203 standard mentioned within NZS 4297. Additionally, the design guidelines in NZS 4297 are considered useful by Australian standards as well. In the case of IS 13837, it refers to the IS 1893 part 1:2002 standard for seismic design, while the ASTM E2392-M10 standard specifies the need for seismic design following ASCE 7-16. Although not explicitly mentioned within NBC 204, seismic design is covered by the Nepalese code NBC 105, which, in turn, recommends application together with the Indian standard IS 4326 - Code of Practice for earthquake-resistant design and construction of buildings. As can be noted, for designing according to the standards and regulations of a construction made of compacted or poured earth, the designer must consult documents from different countries to achieve a structure with seismic action capacity. For Europe, a possible solution to this situation would be to have a unified code, similar to EN 1998-1, Eurocode 8, Part 1 where there are specific rules for steel, concrete, and masonry buildings that analyse specific design criteria for different construction materials, providing detailed information on design calculations to ensure that structures are capable of resisting seismic forces. This may not currently be possible for earthen construction due to the lack of design methods that are not sufficiently researched, correlated, and unified in the form of clear, accepted, implemented, and legislated regulations at the national or European level.

The current study focuses on the use of local raw material for poured earth as a technique of earth building that uses stabilized earth in fluid form, which is then poured into moulds to create durable earthen walls. The earthen material is quarried from Timis County, Romania, an area with a rich tradition in earthen heritage building. Two different soils, fine crushed sand/gravel and additives were mixed and tested to evaluate the pouring settlement, appearance of cracks and strength to further develop a mix for earthen walls.

To achieve the objective, the poured earth must meet in the final stages of the research four main requirements:

It must have high fluidity to be poured/pumpable and ideally self-compacting.

At the time of pouring into moulds, it should exhibit a liquid-solid transition behaviour allowing the wall to support its weight after a short drying period. Additionally, the minimum mechanical strength achieved in the wet state should be approximately 0.07 MPa (Pinel et al., 2017), to be obtained in less than 24 hours, a value close to other materials on the market.

It should be formulated with a general formula compatible with the wide variability of earth-based raw materials. To achieve this, besides the classical analysis of granular correction, the effects on hygrothermal and recycling properties must also be considered, using non-toxic additives.

It should be available at a price that determines costs close to other materials on the market.

MATERIALS AND METHODS

Two types of soils were collected from different areas of Timis County, areas with a rich tradition in earthen heritage building. The grain size distribution of these soils was determined with the combined method according to STAS 1913/5, SR EN ISO 14688-1 and SR EN ISO 14688-2. The results are presented in Table 1.

The inclusion in the ternary diagram was made following NP-074:2022 and is presented in Figure 1.

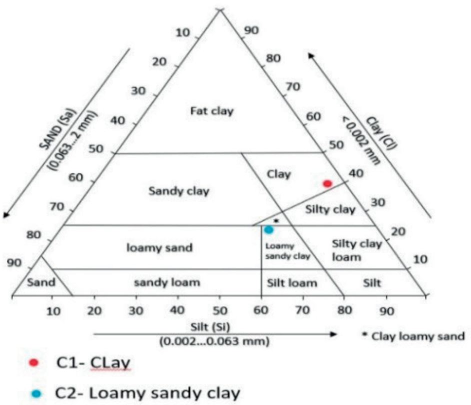

Figure 1. Ternary diagram

Table 1. Determination of grain size distribution through sedimentation

Soil	Clay	Silt	Sand	Gravel
C1	23.50	49.91	26.37	0.22
C2	40.00	56.34	3.66	0.00

The aggregates used are 0/4 mm alluvial silico-limestone, washed sand and 4/8 mm gravel, supplied by a certified quarry.

To reduce the water content and crack a dispersant, Sodium Tripolyphosphate, granular CARFOSEL 996, from Prayon S.A. was used.

With the help of the dispersant, the yield stress and viscosity of pastes can be reduced, and the arrangement of clay particles is more regular with the effect of improving the mechanical strength of clay materials (Rossington et al., 1998).

Normal hydrated lime (HL) was used as a primary additive. Hydrated lime undergoes a chemical reaction with clay particles wherein calcium ions from the hydrated lime displace water molecules and other ions present on the surface of the clay particles upon mixing. This process results in the alteration of soil structure, rendering it friable and granular. Consequently, this transformation enhances the efficacy of soil mixing and compaction processes.

As a secondary additive, calcium lignosulfonate (CL - 48%) concentration and density of 1250 kg/cm^3, was used as a catalyst and producer of ion exchanges in the soil structure (Fernandez et al., 2021).

Tap water, with a temperature comprised between 14 and 16°C, was used for all the experiments.

A detailed process of mixing and pouring (vibrating) is presented in Table 2.

Table 2. Work operations

Work operations	Time [min]
Mixing soil and aggregates	5
Adding water	5
Adding dispersant	10
Conducting settlement determination	-
Pouring and vibrating	-
Weighing process (with formwork)	-
Stripping of samples	24 h/3 days

This preliminary research program was conducted in two stages, the first using mostly soil C1 without the use of dispersant. In this stage (R1-R8) water was added to obtain a settlement of 10-15 cm (S3) for each mix. In the second stage (R9-R_{cam}), the mixing water remained fixed at 18% of the material's mass, with the variation being determined by the percentage of aggregates and dispersant.

Metal moulds measuring 40 x 40 x 140 mm were utilized and kept at 20°C and 50-70% air humidity. From visual observations throughout the drying period, multiple cracks appeared in compositions R1, R9 and R14, leading to their exclusion from subsequent tests.

The consistency of the mixtures was evaluated using the compaction method following SR EN 12350 and classification of settlement according to SR EN 206 by analogy with concrete and the results are presented in (Figure 2).

At 24 and 48 hours after casting, it was not possible to demould the samples as the composition adhered to the mould walls. Demoulding was successfully performed at 3 days after casting without damaging the samples. After demoulding, the samples were weighed to monitor the drying period, with the results presented for each composition in Figure 2 as the mass evolution over time and environmental conditions. The proposed compositions, prepared in stage 1 (R1-R8) and stage 2 (R9-Rcam) are presented in Table 3.

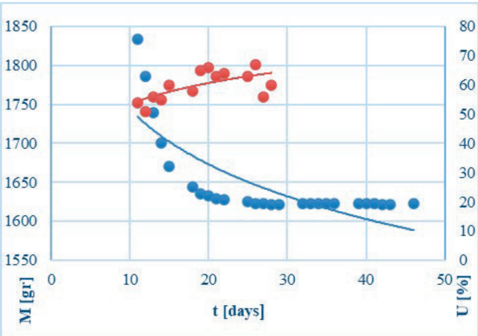

Figure 2. Evolution of drying

Table 3. Compositions

Mix	C1	C2	Sand 0/4 mm	Gravel 4/8 mm	Dispersant % from total mass	Additives %
	%	%	%	%	%	%
R1	-	100	-	-	-	-
R2	75	-	12.5	12.5	-	-
R3	47,5	-	30	17.5	-	-
R4	35	-	30	30	-	5 HL
R5	40	-	30	30	-	-
R6	-	40	30	30	-	-
R7	45	-	20	25	-	10 HL
R8	50	-	25	25	-	-
R9	100	-	-	-	0.2	-
R10	100	-	-	-	0.2	-
R11	75	-	25	-	0.2	-
R12	60	-	40	-	0.2	2 CL
R13	90	-	10	-	0.15	-
R14	-	18	-	-	0.15	-
R_{CAM}	-	25	75	-	-	Straw 1%

After 45 days of drying, for each stage, mechanical tests were carried out to determine flexural and compressive strength by aligning with the mortar standard, using equipment with controlled speed for each determination following SR EN 1015-11, SR EN 196-1.

RESULTS AND DISCUSSIONS

The requirements for pumpable material were met by preparation of mixes R1 to R8 without dispersant with adding water while for the mixes R9 to R13 where percentage of aggregate and the dispersant varies, the compaction goes from S3 to self-compacting.

As shown in Figure 3 the samples were considered dried when the differences between weighing's were lower than 2% taking into consideration the span of air humidity.

The results of the mechanical tests are presented in Figure 4.

In terms of compressive strength, compositions R1 to R9 differentiate based on the percentage of aggregates and the additive (LM) used. The tests from stage 1 indicate the need for the addition of aggregates to complement the compositional matrix and enhance strength, as well as additives that interact with clay particles to form a more stable and stronger matrix.

Using a 10% lime modifier for recipe R7 led to a 100% increase in compressive strength compared to recipe R3. It is essential to investigate the interaction mode of the lime modifier with each soil as well as the saturation curve of clay particles with this additive. In stage 2 the effect of the dispersant on both soil types is highlighted by the increase in strengths across all compositions compared to stage 1 (without dispersant). The addition of additives and fibers resulted in compressive strength values of 2.7 MPa and 1.8 MPa, respectively.

CONCLUSIONS

The study conducted provides evidence of the interest shown by the scientific community for poured earth constructions as a viable alternative to conventional cement-based materials, even in the absence of specific regulations.

Figure 3. Aspects during consistency tests and evaluation of settlement

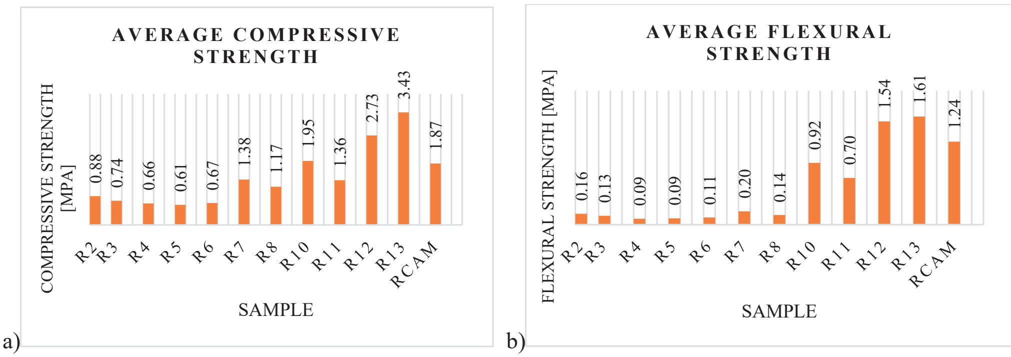

Figure 4. Average a) compressive strength and b) flexural strength

However, further research and development are warranted to establish standardized guidelines and optimize techniques for maximizing the benefits of poured earth construction.

The use of the dispersant in earth compositions has led to settlements corresponding to S3-S5 (pumpable) and an increase in mechanical strengths, with the variation in the water/dispersant percentage being subject to further extensive research.

The preliminary tests carried out show that lignin plays a stabilizing role, enhancing strengths, the percentage variation of which will be subject to further research. Additionally, a combination of both soils mixed with additives could be introduced into the composition.

Given the conclusions outlined, it is essential to persist in research efforts aimed at evaluating the capabilities of compositions and materials incorporating earth. Specifically, attention should be directed towards assessing their ability to meet the necessary strength requirements for both load-bearing and non-load-bearing elements in construction applications. This ongoing research will offer valuable insights into the suitability and potential utilization of earth-based materials in various construction scenarios

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