Alternative stabilisation method for unfired earth blocks

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Abstract. Clayey soils have been used in the construction of buildings since ancient times. It reduces the building's ecological footprint while improving thermal comfort. Soil is a local material that helps people in temperate regions cope with harsh environmental conditions such as high temperatures. The performance of such materials is determined by the soil's chemical composition and physical properties. The main issue with these materials is their high shrink sensitivity and tendency to crack during drying. These pathologies can result in fundamental mechanical performance degradation. The purpose of this work is to investigate various scenarios for the stabilization of compacted soil blocks.In this context, this research investigates the use of alternatives to cement for the stabilization of earth blocks. Sample blocks were constructed using varying concentrations of stabilization materials. The samples' mechanical strengths were assessed. Simultaneously, materials will be compared in terms of ease of manufacture, and financial cost. The mechanical properties (compressive and flexural strength) of stabilized earth blocks shows that the developed mix outperforms the traditional masonry concrete block. The results of this study show that stabilized earth blocks are gaining their place as a viable, sustainable, affordable building material suitable for low-cost housing construction.

1 Introduction

In various forms, raw earth structure dates back several thousand years. Interlocking Compressed Soil Blocks (adobe blocks) have recently proven to be a viable, long-lasting, and cost-effective building material for low-cost housing construction in developing countries.

Earth blocks have a low environmental impact, good thermal properties, a low bearing capacity, and are not susceptible to seismic vibrations. They have a lower embodied energy than traditional blocks, a longer service life, lower costs, greater availability, and ease of handling. However, there have been some concerns raised about their long-term viability. Even though these materials met local strength requirements, their brittleness and limited ability to dissipate energy raise questions about their applicability. To address these flaws and improve the material's specific properties, additives or stabilizers are frequently used. Binders (cement, lime) and synthetic or natural fibers (coconut fiber, oil palm, bagasse, wool, and wheat straw) have been used in earthen construction. Even though synthetic fiber-reinforced soil blocks outperform natural fiber-reinforced soil blocks in terms of mechanical and durability, natural fibers are being used in blocks due to environmental concerns [1]. The study intends to use geopolymeric paste as a potential alternative for the stabilization of earth blocks rather than cementitious materials, which have a high environmental impact. The geopolymer paste is made up of metakaolin and a sodium-based alkaline solution mixed with the clayey soil.

The use of geopolymer in earth blocks research is still in its early stages. These findings are not generalizable and heavily reliant on the materials used [2]. The performance of such materials is affected by the chemical and physical properties of the soil. Metakaolin, which is extracted from natural clay (kaolin) by calcination, is the most well-known source material containing a high amount of aluminosilicate [3]. As a result, the quantity of these materials affects the activation reaction as well as the properties of the produced material [4]. Furthermore, it has interesting physical and chemical properties such as quick hardening, high workability, high compressive strength, fire resistance, and chemical attack resistance [4]. All of these properties can be improved by adding other additives to the mixture. Furthermore, it uses less energy and has a lower environmental impact. As a result, the current study was carried out to investigate several possibilities for earth block stabilization using geopolymer. The environmental impacts of raw earth block production were compared to those of traditional masonry blocks in a study conducted using SimaPro software.

2 Sustainability and Environmental Aspects

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In the construction industry, the term "sustainability" refers to environmentally friendly and green materials [5]. The massive production of cement accounts for 5% of all greenhouse gas emissions each year [6]. Furthermore, millions of tons of waste from the industrial sector, such as fly ash, slag, ceramic waste, and so on, pollute the air and water [6]. However, the world wishes for a cleaner, greener, and more efficient Earth.

When it comes to geopolymer, all of these wastes are recycled into their components, which helps the environment by reducing CO_2 emissions by 22.5% to 72.5%, saving energy used in cement production, and reducing the over-exploitation of natural resources [7]. In general, 1 ton of OPC produces 1 ton of CO_2. The same amount of geopolymer produced, however, emits only 27.5% of the amount emitted by OPC (Ordinary Portland Cement). Furthermore, the temperature required to produce the geopolymer is approximately 50% of the temperature required to decarbonate lime [7]. This demonstrates how geopolymer production can aid in energy conservation.

Geopolymers have demonstrated excellent mechanical and rheological properties, making them a potential alternative to cement in a variety of applications. Compressive strength is affected by a variety of factors and ratios. When the sodium silicate to NaO ratio and the alkaline solids to metakaolin ratio were increased to a certain limit, it generally increased. Furthermore, increasing the aggregate content ratio at a specific rate can increase the compressive strength of the mix [4].

The compressive strength of geopolymer concrete is higher or comparable to that of ordinary Portland cement (OPC), according to various researchers [8]. Flexural strength is a tensile strength measurement that allows an estimate of the resistance to failure in bending for unreinforced beams or slabs. The span length of the specimens used in the test should be at least three times the depth. It is measured using standard test methods such as ASTM C 78 or ASTM C 293. It is expressed as rupture modulus (in MPa).

3 Materials and methods

This study aims to create Clay-based Geopolymer mixes, each having a different percentage of Metakaolin. Then, we'll start taking the compressive and tensile strengths of all the samples with different Metakaolin percentages after 28 days of the sample preparations. The following materials were used for specimen preparation:

- Clayey Soil
- Metakaolin
- Alkali Activator

3.1 Clayey Soil

The soil used in this study came from the Akkar region of northern Lebanon. The apparent density is 1346 kg/m^3, while the specific density is 2368 kg/m^3. The liquid limit (LL) was 40.5% and the plasticity index (PI) was 14.9%, according to the Atterberg limits. The soil contained 45.8% of clay and silt, 50.2% of sand, and 4% gravel.

Figure 1 shows particle size distribution curves from sieve analysis of the particle size distribution of the local soil used for specimen preparation.

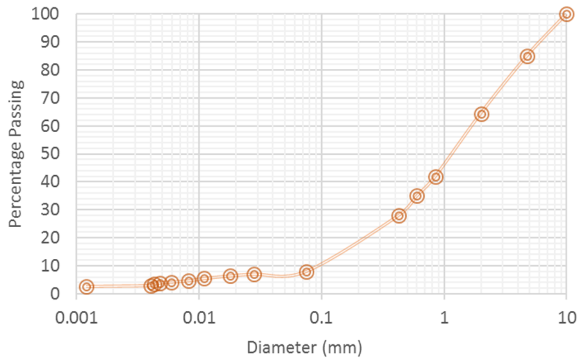

Fig. 1. Sieve analysis of the Clayey soil used

3.2 Metakaolin

Metakaolin MK, according to Shvarzman et al. (2003), chemically reacts with Ca(OH)2 via a pozzolanic method to provide reactive Si and Al. The degree of structural disorder it exhibits has a significant impact on its reactivity [9].

Sabir et al. (2001) investigated the use of metakaolin as a pozzolanic material for mortar and concrete and discovered that it increases early strength while also improving long-term strength [9].

Metakaolin alters the physical properties of cementitious materials, mortar, and concrete, significantly increasing their ability to resist water transport and the diffusion of hazardous ions that have the potential to deteriorate the matrix [9].

Siddique and Klaus (2009) investigated the use of MK as a cement substitute in concrete, and their findings broadly correspond to those reported by Sabir et al. (2001): MK proved to be a useful pozzolan in concrete, strengthening both the early and long-term mechanical properties, limiting water penetration into the concrete via capillary forces, reducing absorption, improving tolerance to sulfate attack, and increasing durability [9].

3.3 Alkali Activator

The reaction of an aluminosilicate precursor with metallic hydroxides (NaOH or KOH) and/or silicates as an alternative cementitious binder is required for the production of alkali-activated or geopolymer-binding materials [10].

Temperature conditions must be met for these chemical reactions to produce products that meet mechanical and durability specifications [10].

Geopolymers are an example of an alkali-activated material because they contain more Al and alkali (Na, K) than Ca. The results of alkali-activation and hydrated

Portland cement, according to Davidovits, differ significantly from those of geopolymerization [10].

It is possible to identify the primary components of their binding gel structures by looking at the presence of OH groups and alkali concentrations [10].

In addition to the importance of the precursor material in alkali-activated/geopolymer composites, the alkali source used has a significant impact on the mixture's characteristics. The highest activity has been observed in silicates, particularly anhydrous sodium metasilicate, which improves mechanical properties. The mechanical properties of silicate-based activators, on the other hand, outperformed those of carbonate-based activators [10].

3.4 Mix Design and Proportions

Five different mixes with the following mass proportions were considered to study the effect of adding an alkali activator and MetaKaolin:
M1: 100% Clayey Soil + Alkali Activator
M2: 95% Clayey Soil + Alkali Activator + 5% MK
M3: 90% Clayey Soil + Alkali Activator + 10% MK
M4: 85% Clayey Soil + Alkali Activator + 15% MK
M5: 80% Clayey Soil + Alkali Activator + 20% MK

First, the clayey soil and MK were mixed dry, and then the alkali activator was added.

Fig. 2. Compressive Strength Test

3.5 Compressive and Flexural Strength

Three samples of each mixture category were prepared for replication. The soil was thoroughly mixed with the appropriate amounts of MK before adding the appropriate amount of alkali activator. The mix's behavior in terms of density, unconfined compressive strength (Figure 2), and flexural tensile strength was then thoroughly investigated.

The results of the unconfined compressive strength test are summarized in Figure 3.

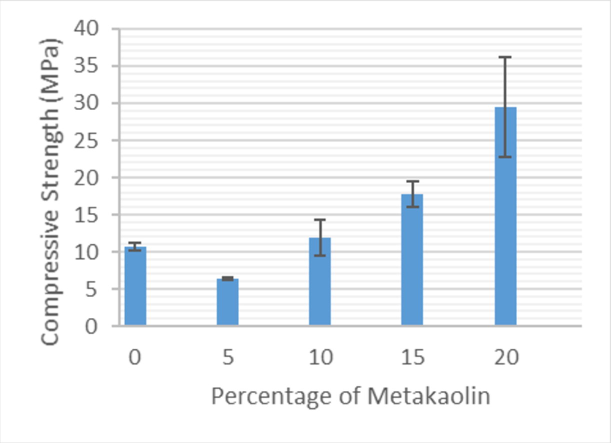

Fig. 3. Compressive strength results at 28 days

The reaction between the minerals in the mix usually gives the mortar its strength. The three main raw materials used were clayey soil, Metakaolin (rich in Si + Al), and the alkali activator.

In Figure 3, we can see that the raw material with no MK produced good f'c simply by replacing water with a Na-based alkali activator. Furthermore, we discovered that the more MK substituted in the clayey soil, the higher the compressive strength f'c.

This can be explained by the geopolymerization process, which requires a specific amount of Si-Al-Na bond. We saw that the 5% had a poor f'c because there was insufficient reaction in the mix design to achieve the best f'c.

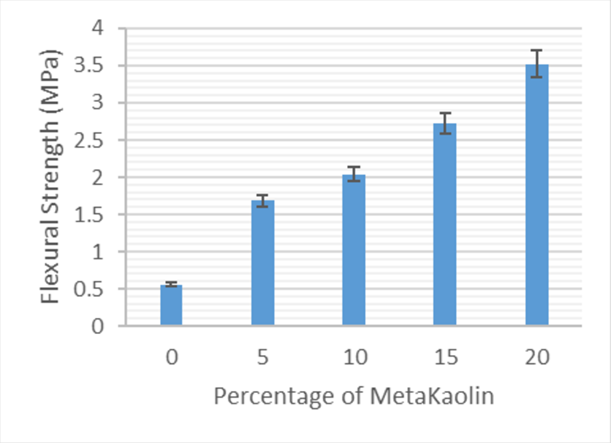

Fig. 4. Flexural strength results at 28 days

The flexural strength reached 2.04 MPa for 10% MK mass substitution (figure 4), which means we increased the percentage of MK in the clayey soil. This value is greater than 0% because the reaction contained sufficient Si2Al to react with the Na-based binder.

The flexural strength increased until it reached 2.72 MPa when the MK percentage reached 15%. Finally, when the MK percentage reached 20%, the flexural strength reached a maximum of 3.5 MPa.

This is generally related to the geopolymerization reaction, which was found to be the strongest at the 20% substitution of the MK due to a large amount of Si and

Al available to react with the alkali activator and fill the space.

3.6 Durability Test

Durability is an important factor that must be researched and investigated. It is critical to ensure that the material used can be used in a variety of settings and locations. The samples were placed in various solutions and settings to mimic real-world situations (water, Sodium Chloride, and sulphuric acid exposures). Throughout the testing process, the physical characteristics of the samples were evaluated.

Every week for 8 weeks, samples are weighed. Finally, these samples were compressed to determine how the conditions affected their compressive strengths.

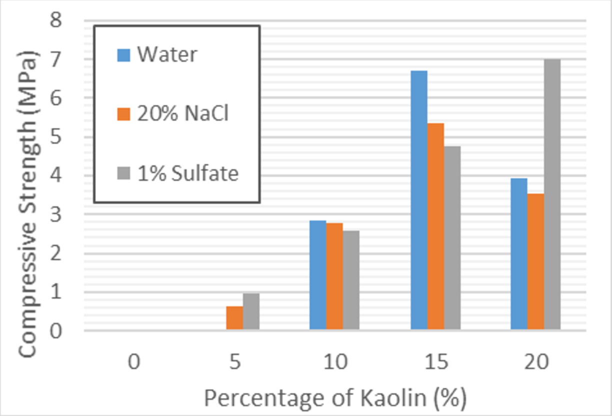

Fig. 5. Compressive strength values at 90 days

Because geopolymer-based concretes are potential replacements for OPC, it is important to see how durable they can be when exposed to real-world solutions and environments. As a result, the samples were immersed in acidic and saline solutions, as well as tap water.

When the f'c of samples (Figure 5) that underwent regular curing at normal temperature were compared to those that were soaked in Sulfuric Acid, it was discovered that the compressive strength of the samples decreased significantly after being submerged in 1% sulfuric acid solution with 0% MK.

The compressive strength increased from 1 MPa to 6.9 MPa when we increased from 5% to 20% (MK).

The compressive strength of the soaked samples was influenced by the NaCl solution. At 0% (MK), we had no compressive strength. At 5% (MK), we notice a slight increase of 0.7 MPa, and at 10% (MK), it increases to 2.9 MPa. We saw a decrease of 20% (MK).

In water, the compressive strength of 0% and 5% MK was zero. f'c increased to 2.8 MPa at 10% (MK) and continued to rise to 6.8 MPa at 15% (MK). At 20%, the strength dropped to 3.5 MPa.

4 Environmental characterization

We concluded from the previous experimental study that the M5 mixture (80% clayey soil, alkali activator, 20% Metakaolin) is the most resistant of the other mixtures. The purpose of this section is to investigate the environmental impact of the content of mixture M5. The manufacturing environmental impact assessment attempts to create an impact profile based on the findings of the inventory. The IMPACT 2002+ technique was chosen as the impact assessment method because it provides an endpoint for all potential impact categories, which are highly desired by the industry [11].

IMPACT 2002+ considers several key categories, including ozone depletion, global warming, and land occupation. The Ecoinvent database and multi-user software SimaPro 8.5.3.0 Analyst [12] were used to model the environmental impact. The experiment was carried out on 1kg of the mixture.

Table 1. Damage assessment of concrete masonry and M5 mixture

Label	Masonry Mixture	Mixture M5
Carcinogens	100	50.6202
Non-carcinogens	100	-6
Respiratory inorganics	57.5739	100
Ionizing radiation	100	24.9385
Ozone layer depletion	100	24.1199
Respiratory organics	79.1049	100
Aquatic ecotoxicity	100	19.4694
Terrestrial ecotoxicity	100	-83
Terrestrial acid/nutri	12.6839	100
Land occupation	0.3661	100
Aquatic acidification	20.8725	100
Aquatic eutrophication	10.4764	100
Global warming	100	38.6126
Non-renewable energy	100	37.8295
Mineral extraction	93.5398	100

The environmental impact of stabilized earth blocks and regular masonry blocks was compared using the SimaPro Software. Table 1 compares the environmental impacts of the manufacturing stage of the life cycle of concrete masonry blocks and stabilized earth blocks using geopolymer.

The results are very positive, as concrete masonry blocks contribute more than earth blocks to all impact categories, with a few exceptions such as "respiratory inorganics", "respiratory organics", "Terrestrial acids/nutrients", and "Land use" impact categories due to the use of clay and Metakaolin.

5 Conclusion

Lebanon is distinguished by a variety of sedimentary formations. Clay is one of the most common types of sediment. There are several types of clay, one of which is green clay. Because sustainability is a major concern in Lebanon today, the purpose of this thesis was to characterize and evaluate the use of green clay in the construction industry. When the clay was used alone, it demonstrated very poor mechanical properties. As a result, the incorporation of an alkali activator and metakaolin (a silica clay-based material) was proposed to develop and test its mechanical properties and durability. The results showed that the higher the mechanical strength, the more metakaolin was incorporated into the proposed mixes. As a result, the alkali silica reaction occurred the more these two materials were available.

The results show that Metakaolin is the most significant contributor to all categories in the manufacturing life cycle stage in terms of environmental impact. Accordingly, the comparative manufacturing stage shows that conventional concrete masonry blocks contribute more than stabilized earth blocks using the geopolymerisation technic for all impact categories except "respiratory inorganics", "respiratory organics", "Terrestrial acids/nutrients" and "Land use" impact categories due to the use of clay and metakaolin.

References

1. S. Hejazi, M. Sheikhzadeh, S.M. Abtahi, A. Zadhoush, Constr. Build. Mater. **30,** 100-116 (2012).
2. S. Manso, W. De Muynck, I. Segura, A. Aguado, K. Steppe, N. Boon, N. De Belie, Sci Total Environ. **481**, 232-41 (2014)
3. A. Hassan, M. Arif, M. Shariq, J. Clean. Prod., **223**,704–728 (2019)
4. L. K. Turner, F. G. Collins, Constr. Build. Mater. **43**, 125–130 (2013)
5. V. Revathy, G. Antherjanam, Proceedings of SECON'19. SECON 2019. Lecture Notes in Civil Engineering **46** (Springer International Publishing, 2020)
6. B. S. Al-Shathr, T. Saleh Al-Attar, Z. Ali Hasan, J. Babylon University, Eng. Sci. **3**, 24 (2016)
7. A. A. Shubbar, M. Sadique, P. Kot, W. Atherton Constr. Build. Mater. **210**, 172–187 (2019)
8. S. Manso et al., Sci. Total Environ. **481**, 1 (2014).
9. F. Wang, K. Kovler, J. Provis, A. Buchwald, M. Cyr, C. Patapy, S. Kamali-Bernard, L. Courard, K. Sideris. (2018).
10. H. S. Gökçe, M. Tuyan, M. L. Nehdi, Constr. Build. Mater. **303** (2021)
11. O. Jolliet, M. Margni, R. Charles, S. Humbert, J. Payet, G. Rebitzer, R. Rosenbaum, Int. J. Life Cycle Assess. **8**, 324-330 (2003)
12. M. Goedkoop, M. Oele, J. Leijting, T. Ponsioen, E. Meijer (Creative Commons, 171 Second Street, Suite 300, San Francisco, California, 94105, USA, 2003)