

Strengthening of Earthen Material with Some Binding Materials for Traditional and Contemporary Adobe Buildings

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ABSTRACT

This study investigates the effects on adobe soils of adding varying amounts of gypsum, gypsum-lime, and lime to clay soils of different characteristics for replacing traditional adobe. This research focuses on stabilizing soil to enhance adobe's structural integrity, making it a feasible option for modern constructions and renovations. The study investigates four types of clay soils with varying mineralogical compositions to produce adobe with different qualities. Results indicate that the introduction of gypsum contributes to reduced unit volume weight, increased void ratio, decreased thermal conductivity, and enhanced compressive strength. The research assesses the impact of water on adobe, including capillary rise and resistance to sprinkling. Moreover, the study explores the potential of gypsum-adobe to address the increasing demand for affordable and sustainable housing, especially in rural areas, contributing to energy conservation and cost-effectiveness. This study presents the advantages of utilizing adobe produced by this method in rural regions, in comparison to the building materials it may substitute.

Keywords: Adobe, earthen material, strengthening, binding materials, gypsum and lime

1. Introduction

Soil is one of the oldest building materials human beings used when seeking solutions to their shelter needs. The ruins unearthed during archaeological excavations in the Çatalhöyük region of Konya and the Çayönü region of Diyarbakır dated to the Neolithic Age (8000-6000 BC) are the oldest examples of soil being converted into adobe and used in building structures. The findings show that this technology was used uninterrupted in the following millennia and that mud brick building production continued until recently.

Adobe has been used especially in the central and eastern regions of Anatolia. It evolved and developed over time, was adapted to the requirements of the age, being used as the main building material of the people of the region. While single-story and generally simple single-room buildings without windows were encountered in the early periods, multi-story adobe houses with advanced floorplans and functional solutions, as well as extremely successful detailed solutions equipped to meet all the expectations of the local people have been built in recent times.

By the second half of the 20th century, the spread of industrial building technologies in Anatolia, especially reinforced concrete, led to adobe buildings like all traditional building types no longer being preferred. Thus, mud brick settlements, which had been an important component for the 10 millennia of Anatolia's cultural history, were abandoned one after another and entered a rapid extinction. However, scientific and technical research shows that improved adobe can be used safely as a building material in contemporary buildings and restorations. This research is an experimental study carried out to contribute to studies targeting the contemporary and traditional uses of adobe.

The aim of stabilizing soil with gypsum and using the improved adobe obtained in this way in large areas has been to find a viable and valid solution that does not contradict the real need to improve the structures in rural settlements and bring them to a level worthy of today's people.

Improving rural structures has not been a common issue of Türkiye but rather a complex, multifaceted issue that has become urgent to solve. In this regard, this article believes that a sound solution can be achieved by using the strong interest rural people

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in Türkiye have of owning a home, their deep-rooted knowledge of traditional building methods, and their interest in adopting innovations whose methods and processes have been demonstrated and whose benefits they trust as a motivation and tool to ultimately create an opportunity to use the natural local materials with which they are familiar.

Formal and superficial approaches make problems more complex and difficult to solve. At a time when the need for balanced growth and development at the national level is being recognized and addressed, the need to improve housing and agricultural buildings is evident in rural areas. In addition, the rural population is growing significantly, although its rate is gradually declining. In today's world where the needs of rural people are increasing, the desire to live in a dwelling worthy of present-day people is considered a natural right. To the extent that this can be achieved, cities can be saved from degenerating into villages by urbanizing villages.

Once the above goal and way to achieve it are recognized, understanding the preference for improving adobe, which is despised in many circles, and dealing with mud instead of looking for more interesting and attractive areas becomes easier when observing problems and selecting research topics.

During this time of increased housing needs all over the world, much research has discussed the possibilities for using soil as a building material and other improvement solutions. The results show that soil granulometric structure is an important factor (Schwalen, 1935). Many methods have been attempted at making soil more stable, mainly through the addition of cement and lime (Bell, 1976; Lunt, 1980). However, no research is found regarding the addition of gypsum or its effectiveness. The fact that people in rural areas of Türkiye use a soil-gypsum mixture as plaster and that gypsum deposits are widespread and abundant leads this study to consider trying this mixture as a building material (İmar İskan Bakanlığı, 1964). Research in various regions of Anatolia has revealed evidence that supports this belief regarding the use of soil as a building material.

The importance of building the exterior and interior walls of a house in a rural area in accordance with current requirements and practices is obvious. Walls should be made of a material that has sufficient load-bearing capacity, is of sufficient quality both in terms of the sturdiness of the structure itself and the health of its occupants, fulfills bioclimatic comfort conditions, minimizes the need for heating, is easy to maintain, has a known or easily learned production and application by the local people, does not require technologies foreign to the region, does not require large investments or complex equipment for its production, and can be used in the structure with a minimum consumption of energy regarding the transportation and production of raw materials and finished products.

Comparing Adobe with Other Building Materials

Considering both the use of bricks or concrete briquettes by the public sector in new construction in disaster areas, and the fact that considerable demand exists from the public to use this type of material to improve their houses, the production and transportation of sufficient materials to meet housing needs appears to be an important energy consumption problem. A survey of plans used in disaster areas and of existing houses shows that an average of 150 m² of exterior and interior walls are used in a house. A 20 cm thick load-bearing wall requires 30 m³ of building material. According to several sources, an average of 8 tons of good quality industrial coal or 3.5 tons of fuel¹ is required to fire the bricks needed for such a wall. In addition, it takes an average of 175 liters of fuel to transport 30 m³ of material from the factory to the construction site, plus vehicle costs. If the walls of the same house are built with concrete briquettes, 6 tons of cement are needed for solid briquettes and 3 tons for hollow briquettes.² To produce this amount of cement, 1-2 tons of coal will be used, and the cost of cement and aggregate transportation will be about the same as for the bricks. In contrast, gypsum-improved adobe can be produced with much less energy.³ Constructing 30 cm thick exterior walls and 20-30 cm thick interior walls is appropriate in a building with improved adobe.⁴ In this case, the same house will have about 40 m³ of wall. As will be discussed later, adobe with 10% gypsum content provides good results, assuming that soil with the appropriate granulometric composition is selected. About 4 tons of gypsum are needed for 40 m³ of adobe, and 0.640 kg of the same coal is used to make it (Papadakis & Venuat, 1970). Having one-third of the 75,000 dwellings to be renovated annually in rural areas under the Fourth Five-Year Plan be built with these types of materials will make a significant contribution to the country's fuel economy. In addition, the use of adobe can greatly reduce the amount of fuel needed to heat these houses, with these values summarized in Table 1.

As stated in the development plan and other official documents, the required number of houses are being built each year in urban and rural areas. The housing shortage grows every year. Many articles on housing address different aspects of the problem. Lack of sufficient and necessary materials and high costs are considered the main causes of the housing deficit. In addition to this

¹ According to the literature and brick manufacturers, 1 kg of bricks requires 500 kcal for drying and firing.

² The production of 1 kg of cement consumes 830-1,400 kcal.

³ For the production of 1 ton of gypsum, 500 kcal is required.

⁴ Construction with the proposed adobe will be done on site and the associated values will be determined as a result of further research.

Table 1. The amount of coal needed to heat houses

Material	Coal consumed for the materials for 1 house (tons)		Coal consumed for 25,000 houses (tons) ^a	Thermal conductivity Coefficient kcal/mh°C ^d	Heat loss of 1 house ^e	Annual coal consumption ^f (tons)
	Solid	Hollow				
	Solid	8.5	213.75	0.68	495	11.5
Brick ^b	Hollow	7.140	178.5	0.52	382	8.9
Concrete	Solid	2.640	66.0	0.55	400	9.3
Briquette ^c	Hollow	1.170	29.25	0.48	365	8.5
Adobe Mixed With Gypsum		0.001	22	0.45	280	6.0

^a Good quality lignite with a yield of 4500 kcal/kg; ^b Vertical perforated load-bearing block brick; ^c Lightweight concrete load-bearing block; ^d Thermal conductivity coefficient, unit kcal/mh°C, values from DIN 4180; ^e Approximately 12% of the facade of the dwelling is assumed to have windows of the same type and in the same area. Based on 100 m² of a cavity-free exterior wall. Cement-lime plaster in brick and briquette and gypsum-soil plaster in adobe are assumed to have the same thickness; ^f The type of coal used in production is assumed to be also used for heating. The annual heat loss value is based on the table in the Ph.D. thesis of Eng. İhsan Gülferi, MSc.

quantitative deficiency, another important point that is almost never addressed is the loss of material and labor due to the repair of damage caused by the inadequate physical quality of the houses being built. Adequate physical quality is easily achieved in adobe buildings, and the need for repair will not be significant. Experiments have shown that the mechanical and physical properties of adobe properly mixed with gypsum are adequate for the structure. Average compressive strength can exceed 40 kgf/cm². The low shrinkage and unit weight of the gypsum adobe indicate that a durable gypsum skeleton has formed within the adobe and that the material is more porous than normal adobe. This means that the new material has a lower and yet-unmeasured thermal conductivity. Several tests have shown adobe mixed with gypsum to gain significant strength against water compared to unmixed adobe and to exhibit positive structural behavior. Adobe wall surfaces can be covered with an adequate quality plaster. This plaster should be thick and not easily detached from the wall, and the best examples of how and with what materials such plaster may be made can be found in abundance in old houses. Suffice to say, in the regions of Sivas, Çorum, and Kastamonu and their very harsh climates, the external plaster is made with a mixture of gypsum, lime, and earth. This study believes that the ongoing research on these forms of plaster will have much to teach.

2. Materials and Experiments

Soil

Four types of clay soils with different appearance and mineralogical composition were selected in the vicinity of Istanbul to produce adobe of different quality by adding gypsum and lime to the soil in different proportions. These include:

- Uskumruköy clay soil
- Kilyos roadside brown clay soil
- Topser yellow clay
- Taşkışla (ITU central building) garden soil

The soil constants for these soils are given in Table 2.

The Uskumruköy clay soil was excluded from the tests due to its high shrinkage and low plasticity, as well as cracking during drying. The remaining soil samples were named according to the way they were treated during the tests. The moisture content of the air-dried soils stored in the laboratory was 3.9%-4%. The proportions of water, gypsum, and lime added to the samples were calculated based on dry soil. The water required to mold the samples was controlled for consistency using a Vicat apparatus. Six samples of 7x7x7 cm³ each were prepared by adding gypsum to Kilyos brown soil and Topser yellow clay (in raw and corrected form) at rates of 0.00, 0.05, 0.10, 0.15, and 0.20 gypsum-to-dry soil; by adding lime to garden soil (in raw form only) at rates of 0.05 and 0.10 lime-to-dry soil; and by adding lime to garden soil sludge with 10% gypsum at rates of 0.025 and 0.05. The same ratios were prepared for 8 samples of 15x15x12 cm³ with garden soil and achieved positive results. To ensure correlation, 24 pieces of the 0.10 gypsum batch were prepared. The samples were air-dried to a constant weight. The granulometry curves of the mixtures are given in Figure 1.

Table 2. The soil constants for soils

Soil properties	Uskumruköy	Kilyos	Topser	Garden Soil
Liquid limit %	102.0	95.0	50.0	35.5
Plastic limit %	43.6	51.0	23.7	27.5
Plasticity index %	58.4	44.0	22.7	8.0
Shrinkage limit %	20.0	17.0	17.4	15.0
pH	6.7	5.6	5.8	5.9
Unit volume weight g/cm ³	2.82	2.72	2.77	2.75
Color	Dark brown	Brown	Yellow	Khaki
Element %	Gravel	8	-	25
	Sand	7	10	15
	Silt	50	65	54
	Clay	35	25	31
Main clay mineral	Montmorillonite		Kaolinite	Kaolinite
Others	Manganese	Bentonite Bauxite	Limonite	Quartzite Plagioclase

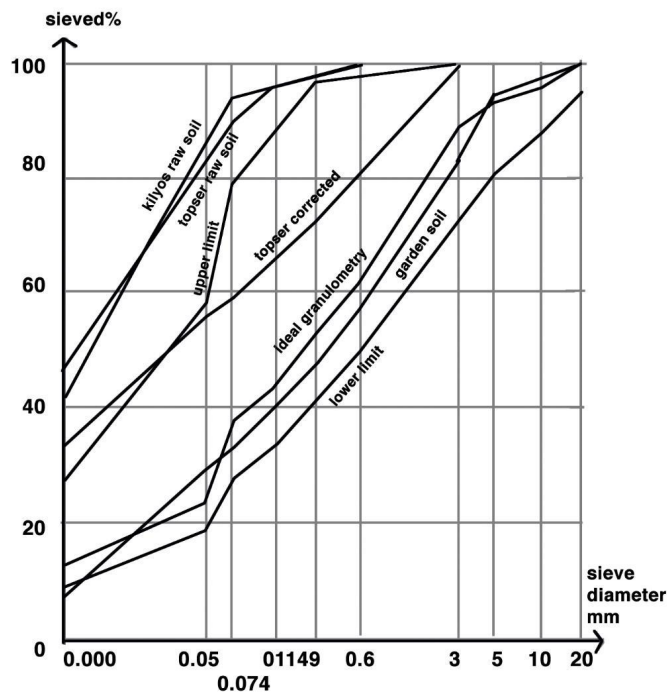


Figure 1. Granulometry curves.

Gypsum

The gypsum added to the adobe is gypsum with a normal consistency of 0.60 water/gypsum, with the unit volume weight and mechanical properties shown in the graph in Figure 2 and the possible addition of a setting retarder.

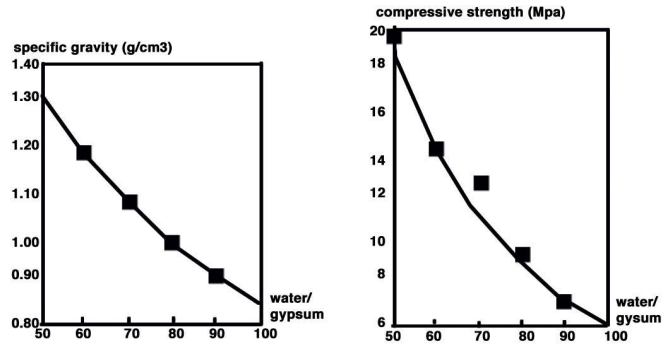


Figure 2. Changes in specific gravity and compressive strength of gypsum based on the water:gypsum ratio.

Lime

Slaked bag lime from the Zeytinburnu Cement and Lime Factory in Istanbul was used.

Tests

Shrinkage

The adobe mud was poured into the molds and dried, their dimensions were measured, and their length changes with respect to the mold dimensions were calculated as a ratio to their initial lengths. The results are shown in Figure 3.

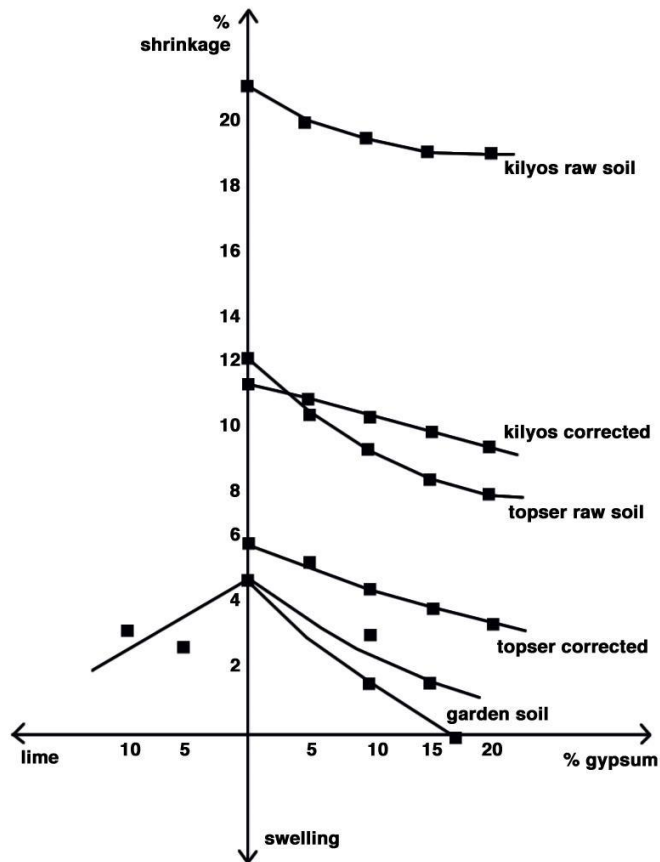


Figure 3. Size change of soil types according to granulometric correction and additive types and ratios.

Compressive strength

One 7x7x7 cm³ and one 15x15x12 cm³ sample were kept as a reference and the others were plastered with gypsum on the top and bottom surfaces; their compressive strengths were then measured using a 100 kN universal HPL testing machine. During the tests of the larger samples, deformations were determined with a 1/100 mm dial indicator. The samples were loaded so that the force was 20 kN or 1 MPa per minute. Average compressive strengths for the different soil and gypsum ratios are shown in Figure 4. The results from the large samples and stress-dependent deformation curves are presented in Figure 5.

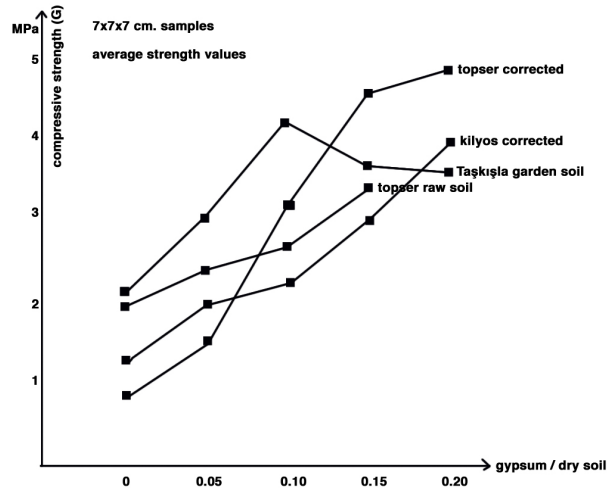


Figure 4. Average compressive strength variation according to concentrated soil and gypsum ratio.

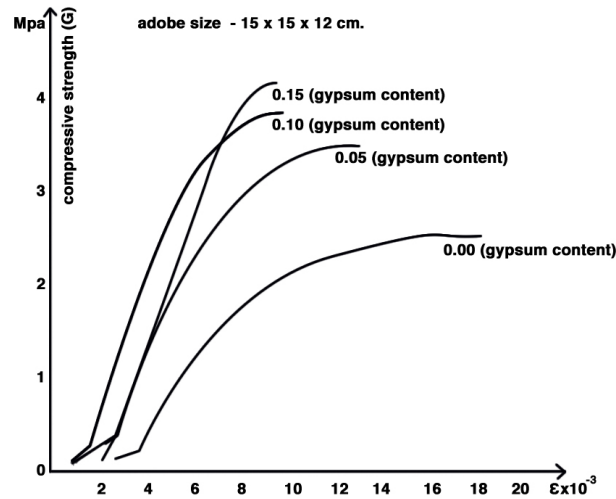


Figure 5. Compressive strength and stress-deformation curves based on gypsum content.

Thermal Expansion

The adobe samples cut in 1x1x4 cm dimensions from the separated test samples were heated from ambient temperature to 500°C in the dilatometer, and the length changes of the samples were recorded. Although slightly different from each other, the samples showed practically the same characteristic size changes based on the gypsum ratio with a very low coefficient of expansion. Thermal strain curve of adobe is shown in Figure 6.

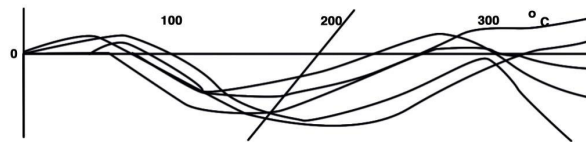


Figure 6. Thermal strain curve of adobe.

Effect of water on adobe

Water rising

The bottoms of the 0.00, 0.10, 0.15, and 0.20 gypsum-to-soil prisms for the 4x4x16 cm³ samples of garden soil were placed in contact with water to observe how water rises in the adobe over time. The relationship between water absorption and porosity of the samples is shown in Table 3. Water absorption test results are shown in the photographs in Figure 7.

Table 3. The relationship between water absorption and porosity of the samples

gypsum/soil	0,00	0,10	0,15	0,20
porosity	0,39	0,42	0,43	0,44
time to water rising	x 10² s			
2,4	1,0	1,0	1,0	1,0
36	2,7	3,0	3,3	3,4
165	collapse	6,2	7,0	7,5
792	-	10,5	12,5	13,0



Figure 7. Water absorption test.

Sprinkling effect

A wall was built by placing three of the large mudbricks of garden soil with gypsum on top of each other. This wall was sprayed with water for 10 minutes from a distance of approximately 1 m at a flow rate of 0.26 L/s through a shower head. This treatment was repeated for three consecutive days, and at the end of the test, the effects of water impact on the samples were observed. The results are shown in the photographs in Figure 8.



Figure 8. Sprinkler test results: Starting on the left are shown the samples with 0, 0.10, 0.15, and 0.2 ratios of gypsum added in the front row; the same ratios are shown in the middle row but with 0.05-0.10 lime added, with the rear row showing the 0.00 and 0.10 gypsum adobe with 0.025-0.05 lime.

3. Discussion of Test Results

Because gypsum adobe production is uncommon, this topic is not found in the literature, and thus the results could not be compared with other studies. However, studies are found on adobe reinforced with cement, lime, bitumen, and organic as well as inorganic fibers. Homogeneously mixing the soil with powdered binders is a challenge. When testing the gypsum mixed with soil, the very fluid consistency of the gypsum mixed with plenty of water allowed it to mix easily with the dry soil. Higher strength blocks are obtainable by compressing the dry adobe soil prepared in this way using simple presses (Lunt, 1980; Penton, 1941). The setting effect of the gypsum added to the soil is realized at rates over 0.10. The solidification of the block as the gypsum set made it easier to remove from the mold and transport. As the gypsum set, a gypsum skeleton formed between the clay particles, reducing the shrinkage of the adobe during drying and creating a hollow structure that easily releases water vapor.

The mineralogical and granulometric properties of adobe soil have a great influence on the properties of adobe blocks.

Increasing the percentage of gypsum in the adobe resulted in:

- Decreased unit volume weight
- Increased void ratio
- Reduced thermal conductivity due to the void ratio
- Increased compressive strength
- Increased water rise with capillarity, but increased resistance to sprinkling.

The adobe produced under typical conditions and from soil with good granulometry was found to have a strength of about 2MPa (20 kgf/cm²). However, this adobe deforms considerably under load. As the proportion of gypsum added to the adobe increases, the strength can reach 4-5 MPa (50 kgf/cm²). This value can increase to 6-7 MPa when the adobe is formed with simple hand pressing. This strength value is even higher than a mortar brick, which has an average strength of 3.5-4 Mpa (40 kgf/cm²).

Slaked lime added to the adobe soil and to the 0.10 gypsum adobe mud caused a decrease in strength and an increase in deformation, contrary to what was reported in the literature (Lunt, 1980). However, this mixture is more resistant to the effect of sprinkling than the adobe without the admixture and the adobe with the 0.05 admixture. In all adobe samples, negligible deformation was found in response to temperature changes.

4. Results

Both the ever-increasing cost of energy and the huge housing shortage make the use of soil imperative, as it is a material whose properties can be enhanced and improved. The proposed method is energy-saving, does not require new technology, and does not increase costs. Therefore, it complies with the principles of improvement methods. Using this method will allow houses to be built in rural areas much cheaper than similar houses made of other materials.

Using gypsum adobe removes the need for expensive and complex equipment, investment, and capital to produce materials. Gypsum adobe can be produced with 99% less energy consumption compared to other materials of the same quality (e.g., solid or hollow bricks, concrete briquettes).

By adding gypsum to the soil, the drying time and the drying area of the adobe are reduced, which facilitates molding and allows a robust structure to be. In this way, a strong, breathable, humidity balancing, bioclimatic, comfortable, and fireproof wall material with high strength and low thermal conductivity compared to normal adobe can be obtained.

A robust building can be constructed with gypsum adobe by determining the street level, considering both the possible water rise in the construction area and the maximum height rainwater splashing can reach, placing it on a good foundation, and starting the adobe wall after reliably insulating it against water and moisture. This will eliminate the well-known disadvantages of adobe and make it a sustainable material for use in the construction of adobe houses in rural areas.

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