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The using of waste phosphogypsum and natural gypsum in adobe stabilization

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Abstract

The best known disadvantages of adobe are its low mechanical properties and poor resistance to water damage. In this research waste phosphogypsum (PG) and natural gypsum were used as stabilization material to improve the properties of adobe soil and to reduce its disadvantages at least partially. The compressive and flexural strength, softening in water, drying shrinkage and unit weight values were determined on adobe samples. The strength values of adobe samples increased with both gypsum additions. The most resistance of the adobe samples against softening in water was obtained with 25% PG addition. Drying shrinkage of test samples reduced with increasing PG content. The dry unit weight of the specimens was not in the recommended range specified in the standards. Test results showed that PG can be used as alternative material in adobe stabilization to bring economy and to reduce environmental pollution.

Keywords: Adobe; Phosphogypsum; Gypsum; Adobe stabilization; Compressive strength

1. Introduction

Adobe is one of the oldest and most widely used building materials in the world. Adobe, or as it is called in Turkey "kerpic", has been a traditional construction material especially in rural regions because of its simplicity and low cost. In addition to these, adobe construction has other advantages as well, such as good thermal and acoustical properties. Adobe also is an ecological building material as it uses natural elements. At the end of a building's life, adobe can easily be reused by grinding and wetting or returned to the ground without any interference with the environment [1–3].

Despite all these merits, adobe has some serious disadvantages such as low mechanical properties and poor resistance to moisture and water attack. In the last decade, there has been considerable work carried out on the improvement of earthen materials. Most of these researches are generally focused on the improvement of its physical and mechanical properties by addition of binders and stabilizers. Protection against water usually requires expensive industrial materials containing cement, lime, asphalt and/or bituminous material [4,5]. By-products and recycle materials are also used in adobe stabilization [6,7].

In the present research, a study is conducted by using the industrial by-product phosphogypsum (PG) and natural gypsum as stabilization material for adobe production. Phosphogypsum is a by-product of chemical reaction whereby sulfuric acid is reacted with phosphate rock to produce the phosphoric acid needed for fertilizer production. PG has used as set controller in the manufacture of Portland cement, as a raw material for clinker, as a secondary binder with lime and cement and in production of artificial aggregates and in road stabilization. A small amount of this waste is used in soil and road stabilization and the remaining are usually deposited in open areas or dumped to river or sea [8–11]. The average annual production of PG in Turkey is about three million tons. The lack of utilization possibility of PG in the country causes economic loss and environmental pollution. Considering the difficul-

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ties of obtaining natural stabilization materials, PG can be used as an alternative stabilization material.

The enormous volume of unused PG can be reused by combining fly ash, lime and Portland cement in the building industry. However, environmental concerns have been surfaced in the past 10 years due to the presence of radionuclides in PG. PG contains naturally occurring radioactivity and ^{226}Ra is a major source of radioactivity. PG that exceeds 370 Bq kg^{-1} (10 pCi g^{-1}) of radioactivity has been banned from all uses by the Environmental Protection Agency (EPA) since 1992. EPA revised the standard to permit its use but the safe limit was set to 10 pCi g^{-1} and the international limit prescribed by European Atomic Commission (EURATOM) is 500 Bq kg^{-1} (13.5 pCi g^{-1}) [12,13].

There is no unanimity on the safe limit for the radioactivity exposure due to PG. The phosphate industry has been searching different ways of reducing the size of PG stacks. Researchers have also been seeking new application areas for PG use as studies have indicated that it would be more environmentally sound to use by-products rather than to dump them.

In today'world, there is an ever increasing demand for construction due to population expansion and shortage of building materials. Utilization of various industrial wastes such as phosphogypsum not only solves environmental problems but also provides a new resource for construction industry.

2. Materials

In this research, a comparative study is conducted by using waste phosphogypsum (PG) and natural gypsum (NG) as stabilization material in the production of adobe samples. For this purposes, a local soil obtained from Cagis region in the city of Balikesir was selected in adobe production. Tests were performed on the selected adobe soil according to relevant Turkish standard [14]. The properties of adobe soil are reported in Table 1. The selected adobe soil has a liquid limit of 56.41% and a plasticity index of 20.70% and hence could be classified as an A-7-5 soil according to AASHTO system [15]. The optimum water content for the soil without stabilization was obtained by using a standard Proctor mould and was 37.70% and maximum dry weight was 13.64 kN/m^3.

PG used in the study was obtained as a by-product during the production process of phosphoric acid from phosphate rocks in Bandirma-Turkey Fertilizer Factory. The chemical compositions of waste phosphogypsum and natural gypsum are presented in Table 2. The specific gravity of PG is 2.89, the optimum moisture content is 13% and the maximum dry density is 14.70 kN/m^3, based on the standard Proctor compaction. The maximum size range is 0.5–1.0 mm. PG can be classified as a silty soil, an A-4 or ML soil, with little or no plasticity. The results of radioactivity analyses of PG determined by the Turkish Atomic Energy Association (Cekmece Nuclear Research and Training Center) are ^{226}Ra: 22 Bq kg^{-1}, ^{238}U: 9.0 Bq kg^{-1}, ^{232}Th: 1.0 Bq kg^{-1} and ^{40}K:11 Bq kg^{-1}. Measures carried out on the radioactivity of phosphogypsum from Bagfas fertilizer plant permit its classification as a weakly radioactive material.

Table 1
The properties of adobe soil

Property	Soil
Classification	
AASHTO	A-7-5
USCS	MH
Atterberg limits	
Liquid limit LL (%)	56.41
Plastic limit PL (%)	35.71
Plasticity index PI (%)	20.70
Grain size distribution	
Gravel (>4.76 mm) (%)	1.00
Sand (0.074–4.76 mm) (%)	18.00
Clay and silt (<0.074 mm) (%)	81.00
Proctor test	
Optimum water content w_{opt} (%)	37.70
Maximum dry weight $\gamma_{d\,max}$ (kN/m^3)	13.64
Specific gravity	2.44

Table 2
Chemical composition of PG and NG

Constituent (%)	Chemical properties (%)	
	PG	NG
SiO_2	3.44	0.61
Al_2O_3	0.88	0.10
Fe_2O_3	0.32	0.10
CaO	32.04	37.00
MgO	–	–
SO_3	44.67	46.18
K_2O	–	–
Na_2O	0.13	0.30
P_2O_5	0.50	–
F	0.79	–
CaO_{free}	0.81	–

PG was stored in open-air residue areas, and thus the appropriate amount of PG was air dried. The air-dried PG and soil was first passed through a 2 mm-sieve before tests. The required amount of phosphogypsum (PG) and natural gypsum (NG) measured as a percentage of dry soil weight and added to the soil. The materials (soil + PG and soil + NG) were first mixed in dry state for 3 min, and then a controlled amount of water was added and mixed in a mechanical mixer for 2 min. The mixture was then placed immediately in the mold and compacted. The amount of mixing water was determined by considering the liquid limit of the soil. After keeping the specimens one day in the mold, the samples were remolded and turned over every day to ensure a more uniform drying.

3. Methods

A series of tests were conducted to determine the compressive strength, flexural strength, softening in water, drying shrinkage and dry unit weight of adobe samples made with and without stabilizers. For this purpose, cubic and prismatic test samples as shown in Fig. 1 were prepared from each mixture. The compressive strength tests were performed on $5 \times 5 \times 5$ cm cubic adobe samples at 28 days and the compressive strength values were determined by taking the average of three samples. A 3000 kN press was used in the tests with a loading rate of 0.5 kN/s.

The flexural strength test was performed on $4 \times 4 \times 16$ cm prismatic test samples at 28 days. The flexural strength of specimens was determined by a one-point bending test with a supporting span of 100 mm, using a material testing machine with a maximum load capacity of 10 kN.

To obtain the resistance of adobe samples against softening in water, $10 \times 10 \times 10$ cm three cubic test samples were prepared from the (soil + PG) mixtures. The samples were first dried for 4 weeks in the air and then were put in the containers that were filled with water of 5 cm depth for determining the softening in water. The time passed between putting the samples in the container and obtaining sufficient softening was recorded as the softening time. Fig. 4 shows the softening in water test of adobe samples.

The shrinkage tests carried out according to the test developed by Turkish Standard Institute [16] for a comparative evaluation of unstabilized adobe samples and PG-stabilized adobe samples with different percentage of stabilizer. Dry unit weights of PG-stabilized samples were determined according to the test prescribed in the Turkish standards for cement treated adobe bricks [17]. After an air drying period of one week, adobe samples from each group were put in the oven at 105 °C to constant weight. Dimensions of each oven dried adobe samples were measured and by dividing the weight to the volume, their unit weights were obtained. The results of drying shrinkage, softening in water and dry unit weight of adobe samples are given in Table 3.

Fig. 1. A view of adobe samples.

Table 3
The results of shrinkage, softening in water and dry unit weight tests of PG-stabilized adobe samples

Stabilizers PG (%)	Shrinkage (%)	Softening in water (min)	Dry unit weight (kN/m^3)
0	4.20	35	13.04
5	3.39	57	13.13
10	3.15	76	13.37
15	3.06	11	13.51
20	2.88	163	13.68
25	2.49	201	13.69

4. Results and discussions

Waste phosphogypsum and natural gypsum were used as stabilization material to produce the adobe samples. The amounts of additive used in investigation varied between 0% and 25%. The effect of addition of phosphogypsum and natural gypsum on compressive and flexural strength was determined. Dry unit weight, water resistance, and drying shrinkage of PG-stabilized adobe samples were also studied. The compressive strength and flexural strength values of the 28-day adobe samples are given in Figs. 2 and 3, respectively. Compressive strength and flexural strength values of adobe samples increased with addition of both types of gypsum. The compressive strengths of unstabilized and PG-stabilized adobe samples are, respectively, 1.01 MPa and 4.34 MPa at 28 days. The maximum increase in compressive strength value was obtained as 4.34 MPa and 4.72 MPa for 25% PG and NG addition, respectively.

The compressive strength values were obtained as 2.92 MPa and 3.10 MPa for 10% PG and NG addition Binici et al. [18] found the compressive strength as 3.70 MPa for 10% gypsum addition. In another research, Binici et al. [19] found the same values for cement stabilized mud bricks. In the study of Kafesçioğlu et al. [20], the compressive strength obtained as 4.45 MPa at 10% gypsum addition.

The Turkish standard [19] has given a lower limit for average compressive strength of adobe block as 981 kPa (10 kg/

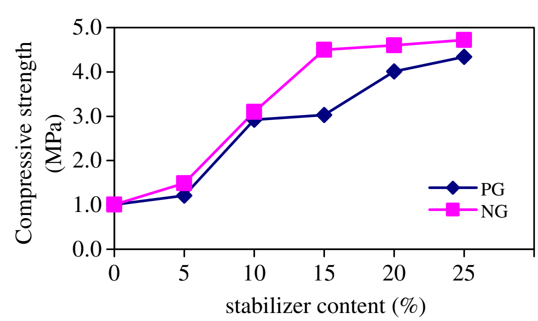

Fig. 2. Compressive strength vs.stabilizers content for PG and NG-stabilized adobe samples.

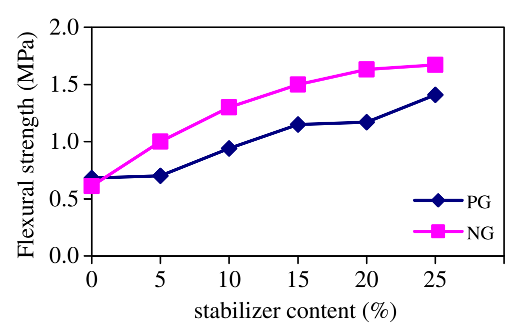

Fig. 3. Flexural strength vs. stabilizers content for PG and NG-stabilized adobe samples.

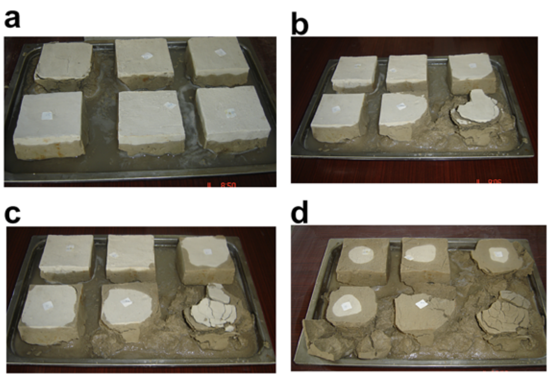

Fig. 4. (a) Softening in water test; immersion in water after 30 min. (b) Softening in water test; immersion in water after 45 min. (c) Softening in water test; immersion in water after 60 min. (d) Softening in water test; immersion in water after 145 min.

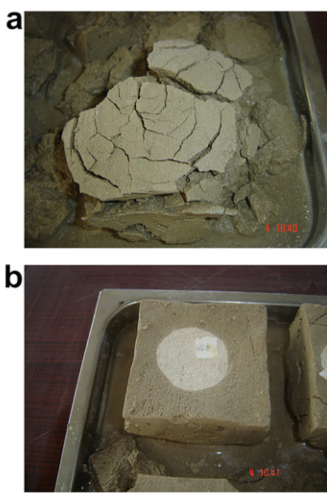

Fig. 5. (a) Unstabilized adobe sample exposure to water after 145 min in the immersion test. (b) PG-stabilized adobe sample exposure to water after 145 min in the immersion test.

cm^2) and has stated that no blocks should have a compressive strength less than 784 kPa (8 kg/cm^2). Also [20], the cement treated adobe blocks should have minimum compressive strength values of 981 kPa (10 kg/cm^2), 1570 kPa (16 kg/cm^2) and 1962 kPa (21 kg/cm^2) with 5%, 7% and 10% cement additions, respectively. It can be seen that the compressive strength of adobe samples made with or without any stabilizers are always greater than the values given in the standards. In this study, a highest compressive strength of adobe samples has been achieved with 25% phosphogypsum and natural gypsum addition. These values were about four times greater than required value given in the standards.

One of the main disadvantages of adobe soil is its low resistance to water. Therefore, the results for softening in water test are important for adobe. In this study, the test results showed that the adobe soil without stabilizers has a softening time 45 min less than the specified time in the standard [19]. The most resistance against softening in water of the adobe samples was obtained with 25% PG addition. It can be clearly seen from Fig. 5 PG stabilized adobe samples have a higher resistance than that of unstabilized adobe samples against of softening in water.

Table 3 summarizes the results of drying shrinkage at 28 days. The addition of PG reduces the shrinkage. The reduction in shrinkage was 25% and 35% for 10% and 20% of PG addition, respectively. A mixture made with 25% PG seems to give the lowest shrinkage.

Addition of phosphogypsum increased the unit weight of the adobe samples. The unit weight of specimens prepared with phosphogypsum addition varied from 13.13 kN/m^3 to 13.69 kN/m^3. According to Turkish standard, the unit weight values of the cement treated adobe bricks are to be between 17.0 and 19.5 kN/m^3. As can be seen in Table 3, the dry unit weight values are less than the value that is given by the standard.

5. Conclusions

The main objective of the present research is to investigate the possibility of phosphogypsum utilization as a stabilization material in production of adobe. The results obtained from the experimental studies can be summarized as follows:

- The strengths of stabilized adobe samples increase with increased contents of stabilization agents. Addition of both types of gypsum in amounts larger than 10% led to an increase in the strength. The compressive strengths of adobe specimens made with various percentage of phosphogypsum are always greater than the minimum required value given in the standards. The maximum increase in strength value is obtained when there is 25% phosphogypsum addition.
- The main deficiency of adobe is its susceptibility to water damage. Adobe specimens prepared with phosphogypsum have a softening time 45 min more than what is described in the standard. However unstabilized adobe samples have the softening time less than 45 min. The most resistance to water was obtained at 25% PG.
- Addition of phosphogypsum and natural gypsum to adobe soil increases the unit weight of adobe samples but the unit weights of all specimens are less than the value given by the standard.
- The use of PG as a stabilization material reduces drying shrinkage. A mixture prepared with 25% PG seems to give the lowest shrinkage values.
- Adobe specimens prepared with phosphogypsum addition have smooth appearance and have low shrinkage value in comparison to adobe samples made without phosphogypsum.
- The soil–phosphogypsum mixtures used in adobe production can also be used as plaster for adobe walls. Hence, uniformity can be obtained by drying with together adobe and plaster.

There is an ever increasing demand for construction due to population expansion and shortage of building materials.

The use of local materials and skills for building has a positive impact on local and regional economies especially in rural areas. Adobe is a good alternative in a country like Turkey because of its adaptation to the local climate and social conditions. However traditional adobe construction does not answer our current need. For this reason, more research needed to improve the engineering properties of adobe. As a result, the use of phosphogypsum as a by-product of gypsum would be beneficial to improve weaker properties of adobe, while at the same time it would be one of many viable answers for handling phosphogypsum waste problem.

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