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IMPROVED PERFORMANCE OF EARTH STRUCTURES BY LIME AND GYPSUM ADDITION

Bekir Y. PEKMEZCİ*, Ruhi KAFESÇİOĞLU and Ebrahim AGAHZADEH*****

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INTRODUCTION

Studies have been carried out to resolve the housing problems of poor people all around the world. Low-priced and fast construction systems, which can be built with local materials, have always been required. Adobe buildings have the capacity to meet this need and are the most suitable systems fulfilling the housing needs of almost 50% of the world's population (Houben, 1994). Interest in adobe buildings, first built in Mesopotamia c. 7000 BCE, has recently increased due to needs for energy conservation, reduced pollution, environmental concerns and increased standards of living. Thus, studies and researchers have gained new perspectives. Adobe buildings have been reevaluated in numerous studies under current conditions and compared with modern materials. Not only are adobe buildings environmentally friendly, but they are also advantageous regarding production and service costs compared to buildings made from burned bricks (CID, 1993, Riza et al. 2010). Adobe constructions, besides their superiority, are criticized as needing repair (Kerali, 2001), having thick and heavy walls, relatively low compressive and shear strengths and in particular the possibility of becoming damaged under earthquake effects (Ural et al., 2011, Maheri et al., 2005). Damages in adobe buildings are associated with material quality, ground motion acceleration, wall slenderness, structural design and geometry which have an effect on building performance (Bariola and Sozen, 1990, Samali et al., 2011). In particular, it is recommended to take precautions to improve the performance of adobe buildings under earthquake risk. Using natural fibers (Vargas et al., 1986, Vega et al. 2011, Lertwattanaruk and Choksiriwanna, 2011), wooden reinforcements or welded steel reinforcements improves the strength of adobe materials and the performance of a building which presents nonlinear behavior. Stabilizing the earth with some additives in adobe manufacture, as well as the use of fibers and reinforcements, presents positive effects on building performance depending on better material performance. Many stabilization methods have been practiced

* Faculty of Architecture, İTÜ, İstanbul, TURKEY

** İstanbul, TURKEY

*** İRAN

from past to present in order to improve material performance. The most significant stabilization method is the addition of lime (Khattab et. al., 2007, Millogo et. al., 2008). Lime reacts with clay and forms C-S-H and calcite crystals as it becomes carbonated in stabilizing with lime (Khattab et. al. 2007, Millogo et. al. 2008). Stabilization with gypsum is also studied (Ahmed and Ugai, 2011). Studies on earth construction materials generally have focused on properties such as compressive strength, water resistance and thermal conductivity. It was reported that the compressive strength of current earth construction buildings varied between 0.5 and 3.0 MPa (Silveira, 2012, Vargas et. al, 1986).

In 1980 at the laboratory of Istanbul Technical University, Faculty of Architecture, promising results were obtained in a research project focusing on earth constructions in order to improve their durability and strength (Kafesçioğlu, 1980). This paper aims to evaluate the performance of existing buildings built in light of research projects since 1980, by using advanced mechanical, chemical and microstructural analysis techniques. Construction earth, where its structural and chemical compositions have been modified by adding gypsum and lime, has been transformed into a new material with improved physical and mechanical properties. Properties, benefits and applications of this wall material, called Alker, have been summarized in this paper.

Like other construction earths stabilized with additives, texture and structure of the product called Alker has been changed becoming an earth-based wall material with improved physical and mechanical properties. The material consists of 8-10% gypsum, 2.5 – 5% lime and 15 – 20% water (dry weight) which were added to construction earth with improved granulometric structure (Kafesçioğlu, 1980). Given mix ratios are by weight of dry earth under laboratory conditions. Converting these ratios into a volumetric scale at construction sites provides ease of application. Gypsum and lime are added to the mixture and it completes setting within 20 minutes, giving rigidity to the material which allows its shape to be kept and preventing clay shrinkage. The blocks can then be demolded after 20 minutes has passed, gaining their rigidity and strength by reactions of lime.

Alker Properties

Properties provided by the complementary activities of gypsum and lime during formation of Alker are summarized as follows.

As setting of gypsum completes in a short period of time, it provides a satisfactory rigidity to the material. Curing and drying processes as well as production and laying areas for drying are not needed, which are important problems for all other similar materials. Due to the early setting time of gypsum, deformation and crack risk to the structure during the drying period is prevented. A new water insoluble chemical formation is created by adding 2.5-5% lime. The product does not become dispersed as plain samples even though it stays in the water for a long period of time.

The satisfactory rigidity created by gypsum in the first stage ensures shape stability of the blocks as the new formations continue developing in the structure.

The production process is very easy and energy consumption in buildings made with this material are minimal. While the buildings are healthy, it also creates a healthy environment for users.

Figure 1. Experimental Building I Preschool

Alker Experimental Buildings

A number of experimental buildings were constructed under different conditions and at different dates in order to verify the results obtained under laboratory conditions (Kafesçioğlu 1980). Working on the production possibilities of Alker under rural conditions and construction techniques were the other aims in constructing the experimental buildings. Results obtained from two of the experimental buildings are explained in the following paragraphs.

Experimental Building I

The first experimental building was built as part of Tanriverdi's study (1984) "Researching and Manufacturing Opportunities of Gypsum-Stabilized Earthen Production". Upon completion of the structure, the building was equipped to serve as a preschool (Kafesçioğlu, 1984). The single story building was constructed with three rooms as well as a kitchen and a bathroom. A floor heating system, which was connected to a water heater in the bathroom, was installed in the building. The energy consumed for heating was recorded daily in order to determine thermal performance of the building for a year. Indoor and outdoor temperature and humidity records were updated weekly. This building served as a preschool for nine and a half years and then was turned into a security office for the University (**Figure 1**).

Results obtained from experimental building 1 are given below;

- The work team was sufficiently prepared within a day by pre-works for the job, which they would perform for the first time and repeat uninterruptedly every 20 minutes.
- The 20-minute period was sufficient to prepare the mixture needed, transfer it to casting place and placing into mold.
- The most suitable method to prepare the mixture was determined as follows. The water, gypsum and lime proportions to be added to the earth were prepared in different containers in using a volume scale. Approximately one third of the water was reserved. The remaining water was mixed well with earth and lime. Gypsum was mixed with the reserved water and added to the earth mixture, then remixed and placed into the mold.
- Colored plaster was applied on exterior walls.
- Gypsum plaster was applied on interior surfaces by a spray machine.

Figure 2. Experimental Building II 15 Years Post Construction (photo by Murat Kafesçioğlu).

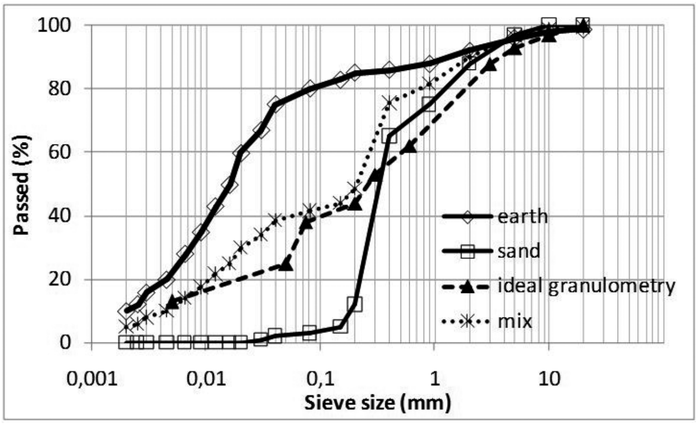


Figure 3. Particle Size Distribution.

Experimental Building II

As a result of experiences obtained during the construction of experimental building 1, a project was developed to construct multiple buildings with the purpose of reducing costs and construction time with mass production. Experimental building project 2 was carried out at İTÜ Ayazağa campus.

A construction site system was organized to utilize engineering equipment such as a concrete mixer, mobile bucket, elevator and compactor in order to determine the practicality of Alker mixture on mass housing projects.

Materials were transported by a wheel barrow and a sledgehammer was used for pressing. A mold, 60 x 90 cm with steel frame and interlocks, was installed on the foundation walls and floor.

The earth, which was taken by wheel barrow measure, and ¾ of lime and water were put in the concrete mixer and mixed for 4 minutes. Then the gypsum, which was mixed with the remaining water, was added in the concrete mixer then mixed two more minutes and the mixture was transferred into the wheel barrow.

The results obtained under these conditions are given in the following paragraph.

Pouring the mixture in the wheel barrow, transporting, casting into the mold and pressing with the sledgehammer were easily done within 20 minutes. The mold was removed as the wall gained sufficient rigidity after 20 minutes. The picture of experimental building II is shown in **Figure 2**.

Behavior of Experimental Buildings Against Various Effects

Experimental buildings were constructed in order to determine the performance of the construction material Alker, earth stabilized with gypsum and lime. Resistance of the material to mechanical effects and outer environmental conditions were also observed on these buildings. Exterior walls of the experimental buildings were exposed to outer environmental conditions in order to observe durability performance under natural conditions. The observations showed no flaking, wearing, collapsing, etc. damage to the building due to freeze-thaw or any other outer conditions. Furthermore, buildings I and II have withstood earthquakes including the Marmara Earthquake in 1999. Both showed no structural damage following the 1999 earthquake. As part of this study, samples were taken from two experimental buildings in the İTÜ Ayazağa Campus in order to understand chemical reactions over time and follow the development of binding gels in earth mixed with gypsum and lime. The determination of crystal structure was carried out by X-ray diffraction (XRD). The results obtained were compared with those from younger samples (6 months old). Also, microstructural analysis was performed with a mercury intrusion porosimetry (MIP) and a scanning electron microscope (SEM) on the samples taken from experimental buildings I and II.

Depending on the promising and positive results obtained at the end of practical applications, following experimental studies were performed on plain earth and Alker samples produced with addition of lime and gypsum in order to understand Alker's physical, mechanical and micro structural properties.

EXPERIMENTAL STUDY

Materials

In this experimental study, Alker and plain earth samples were produced by mixing lime, gypsum, sand and earth with water. The earth, including natural aggregate and natural clay, from İTÜ campus was used to produce the samples. Particle size distribution and hydrometer analysis were carried out on the earth. The aim was to obtain the particle size distribution of the ideal adobe curve recommended for producing the best adobe developed by Arizona University (Schwalen 1935). The earth was mixed with sand to reach the ideal adobe particle size distribution. The particle size distributions of earth, aggregate, 60% earth 40% sand mix and the ideal adobe curve are shown in **Figure 3**.

Mixture Preparation

Four different series of specimens were produced: a plain earth mixture (PL), a 10% gypsum earth mixture (G10), a 10% gypsum 2.5% lime earth mixture (G10 L2.5) and a 10% gypsum 5% lime earth mixture (G10 L5). The water to dry material ratio was selected as 0.20 to ease workability and casting the mixture into the molds. After adding water to the dry mixture, it was rapidly cast into the molds within 1-2 minutes. The molds were kept on a vibrating table for 1-3 minutes in order to set the mixture.

The samples were kept under laboratory conditions for 28 days. Physical and mechanical tests were applied to the samples at the end of the curing period. Physical tests included capillary absorption, unit weight, shrinkage and thermal conductivity. Mechanical tests included compressive and shear strength. Furthermore, compressive strength tests were performed at 1, 6 and 24 hours as well as 7,14 and 180 days. Crystal structures were examined in the hardened adobe by XRD tests. Pore size distribution was determined by MIP tests. The microstructure was observed by a scanning electron microscope (SEM). Microstructural tests were carried out on 6 month old samples.

Physical Tests

Thermal Conductivity

Due to the high thermal capacity of adobe, it is capable of retaining excessive heat during the day and releasing it when the temperature drops. Adobe stabilizes thermal changes in buildings due to this property (Saldivar and Batty, 2006, Kafescioglu, 1987). In order to test temperature stabilization capacity of earth buildings, inner and outer moisture and temperature were recorded for five days in experimental building I in

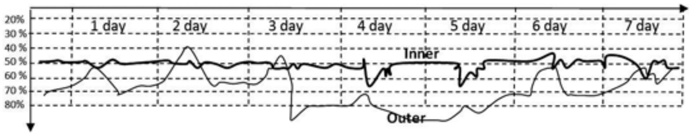


Figure 4. Inner - Outer Moisture.

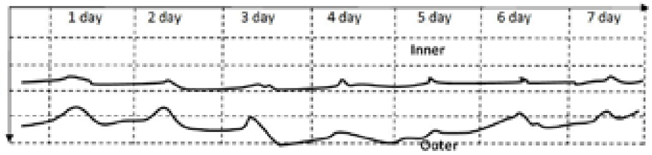


Figure 5. Inner - Outer Temperature.

July 1983. Results are shown in **Figure 4** and **Figure 5** respectively. As demonstrated in the figures, temperature and moisture in the building were not significantly affected by changes in the outer environment. A stable trend was observed for 7 days. Earth construction prevents changes in temperature and moisture in the outer environment from affecting the building interior.

It is necessary to determine the coefficient of thermal conductivity of the earth samples in order to be able to calculate wall thickness during the design process. A test to determine the coefficient of thermal conductivity was carried out on the samples produced in the laboratory. 30 x 30 x 3 cm samples were used in the test. Tests were carried out in accordance with the ISO 8301 heat flow meter method. As a result of the tests, the coefficient of thermal conductivity in Plain, G10 L, G10 L2.5 and G10 L5 samples were 0.390 W/mK, 0.290 W/mK, 0.250 W/mK and 0.216 W/mK respectively. The coefficient of thermal conductivity of adobe samples is much lower compared to concrete. It's thermal conductivity is twice as much as autoclaved aerated concrete, which is used as a wall material for thermal insulation. By using these values and considering the U value, which has to be obtained based on Turkish Standard 825, the wall (31 cm thickness in Turkey Region 1 and 55 cm in Turkey Region 4) produced by using adobe with gypsum and lime (Alker) satisfies the required heat insulation performance. Samples with gypsum have lower heat conductivity values compared to those of plain earth. This value decreases when lime is added. This indicates that gypsum and lime make a contribution to heat insulation.

Capillary Absorption

Capillary absorption was tested on 7 x 7 cm cross section samples. The samples were coated with paraffin, cross sections were prepared, then weight and water level changes were determined. The coefficient of capillarity was not calculated due to a decrease in weight associated with material loss in some samples. The relation between absorbed water in the unit area and the square root of time is shown in **Figure 6**.

Figure 6 shows that, during capillary absorption, the weight of the plain earth sample decreases over time, the weight of the gypsum added sample increases gradually then gradually decreases and the weight of the gypsum-lime samples increase markedly. Dissolving and erosion of adobe bricks without lime and gypsum was observed during capillary absorption, as shown in **Figure 6**. Although a decrease in weight was detected for samples without lime, capillary water suction continued. The capillary water level increased in the block, with the weight loss being related to

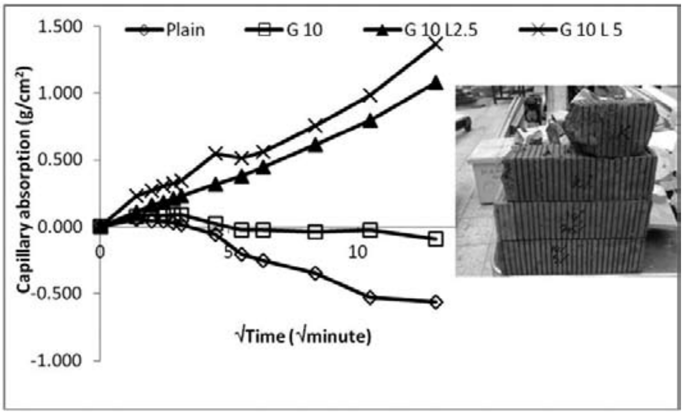


Figure 6. Capillary Absorption.

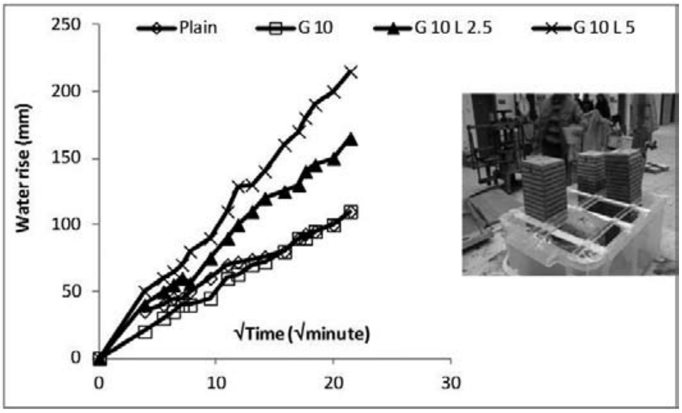


Figure 7. Capillary Water Rise.

the loss of material from the bottom. The weight of the samples containing gypsum-lime increased over time and no erosion was observed in these two samples associated with capillary absorption and water contact.

In order to avoid misleading results due to weight change, capillary water absorption was evaluated with water rise levels.

Levels were marked on every 1 cm of the samples and the time for water to reach each height was recorded. The results obtained are shown in **Figure 7** below. While the water rise rate is highest in the samples containing 10% gypsum and 5% lime, it is lowest in the plain and only gypsum samples. Although capillary absorption levels in the samples with gypsum-lime reached higher values, they had no erosion due to contact with water. The thin and continuous capillary network causes higher capillary suction. The structure formed by products of lime keeps the adobe buildings undamaged due to water.

Shrinkage

Linear shrinkage measurements were done on 50 x 10 x 10 cm prismatic samples. Shrinkage measurements were carried out over 50 days. The samples were kept under laboratory conditions of 20±2 ^{0}C temperature and 65±5% relative humidity. The relation between shrinkage and time is shown in **Figure 8**.

Plain earth samples presented the highest shrinkage value in **Figure 8**. Maximum drying shrinkage values of plain, G10, G10 L2.5 and G10 L5

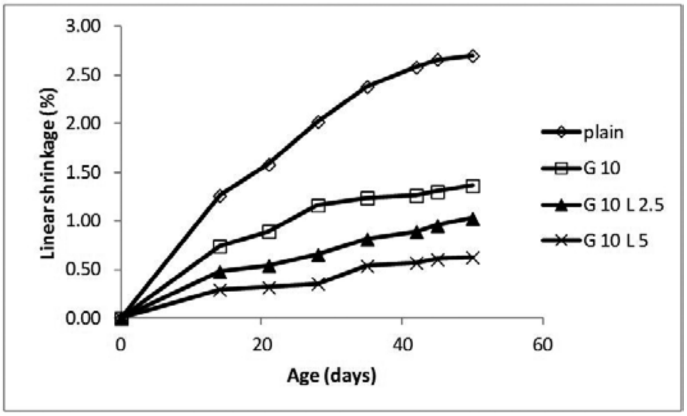


Figure 8. Shrinkage.

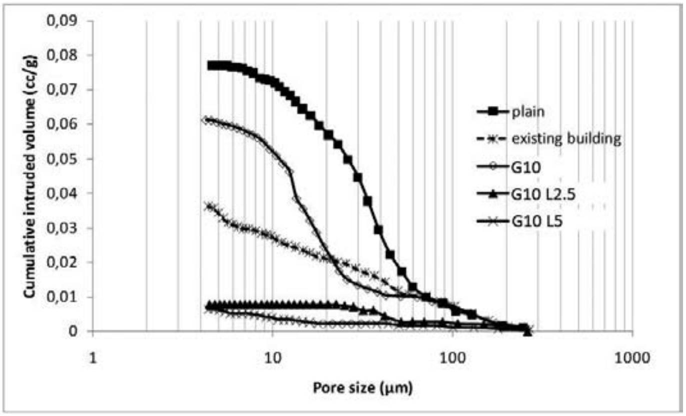


Figure 9. Mercury Intrusion Porosimetry.

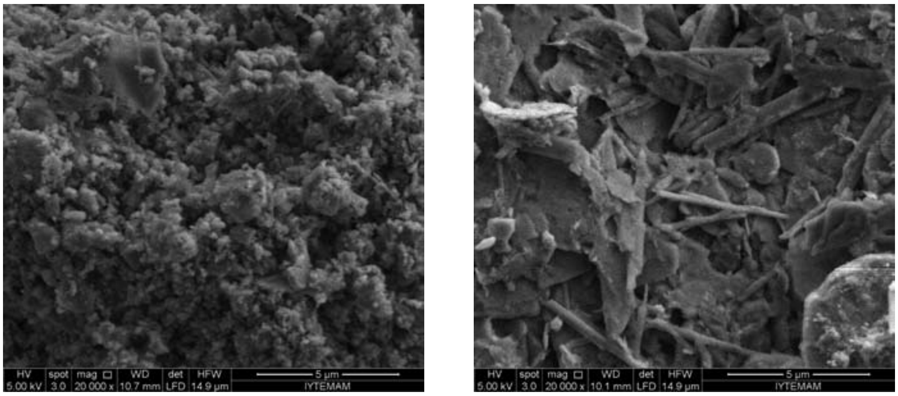
mixtures were 2.7 - 1.3 - 1.0 and 0.6% respectively. Results show that the maximum shrinkage value of the plain mix at 28 days is 4 times higher than that of the G10 L5 mix.

It is known that the shrinkage value of normal strength concrete is approximately 0.10-0.15% (Mehta and Monterio 2006). Shrinkage values of gypsum-lime Alker mixtures are 4 times higher than that of normal strength concrete. A low shrinkage value is quite a significant property of materials, preventing cracks on buildings. Moreover, based on the observations on experimental buildings I and II performed years after, no cracks due to shrinkage have been formed on the buildings.

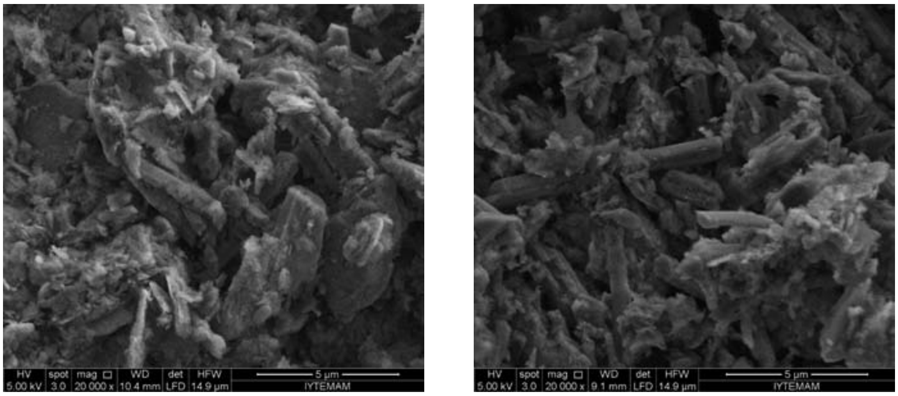
The low shrinkage values and crack free adobe can be attributed to a rigid skeleton formed by a hardening of gypsum and lime in the structure. Calcite crystals and binding gels formed as a result of the pozzolanic reaction also result in lower shrinkage of gypsum and lime adobe samples. Finally, the secondary structure, which prevents deformations from stresses caused by shrinkage, may be an effective parameter in reducing shrinkage values.

Microstructure

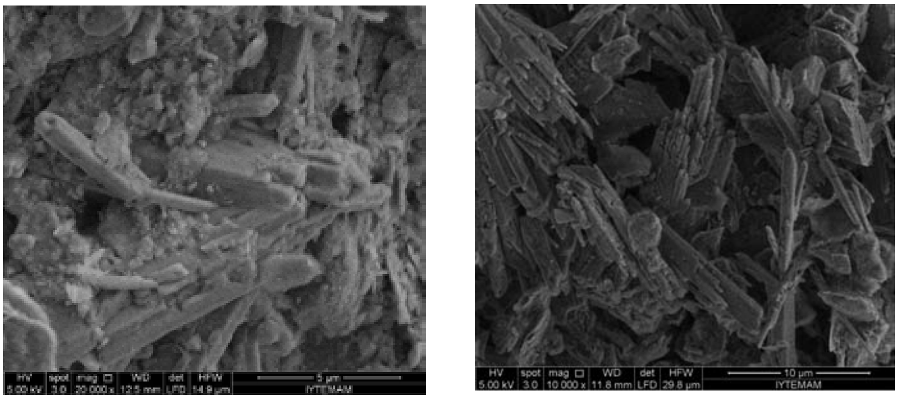
Mercury Intrusion Porosimetry (MIP) was used as a valid method to determine the pore size distribution of stabilized earth (Khattab et. al. 2007). Maximum applied mercury pressure was 48 psi (~331 KPa). MIP test results of samples produced in laboratory and taken from experimental building II are presented in **Figure 9**.



a. Plain earth b. G10



c. G10 L2.5 d. G10 L5.0

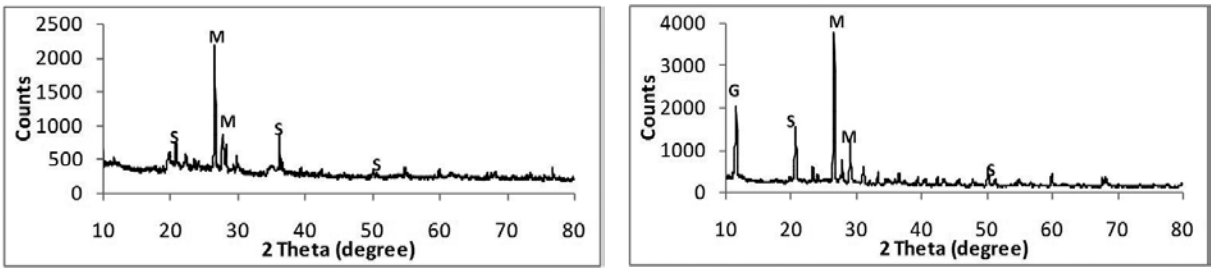


e. Experimental building II f. Experimental building I

Figure 10. SEM Images.

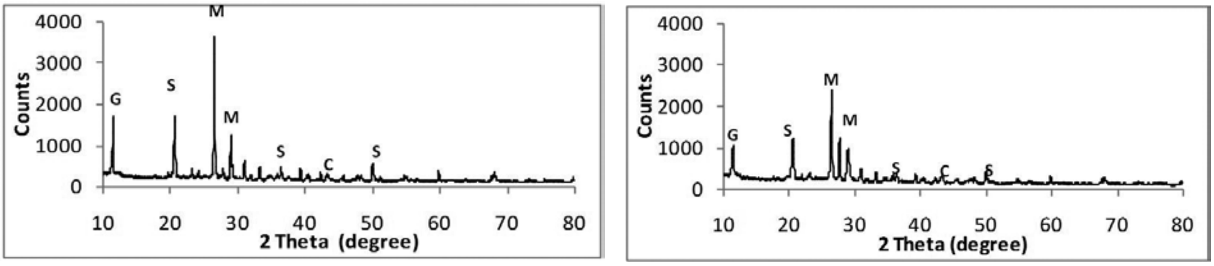
Total pore volume of samples containing 10% gypsum is lower than plain earth but greater than earth with gypsum-lime. This result is due to the filling of the pores by gypsum and lime products. The amount of mercury penetrated in plain samples is greater than that of samples with gypsum and lime. Samples with lime have lower pore volumes over all diameters tested. The experimental building exhibited the lowest pore volume among all the samples.

SEM images are shown in **Figure 10** below obtained from samples produced in the laboratory and samples taken from experimental buildings I and II. **Figure 10a** presents plain earth and a loose structure that can easily be distinguished with individual particles physically bonded without



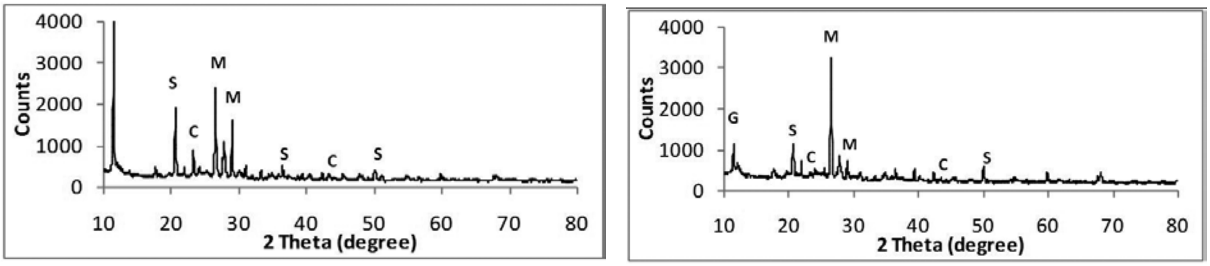
a. Plain

b. G10



c. G10 L2.5

c. G10 L5



f. Experimental building I

f. Experimental building II

Figure 11. X-Ray Diffraction.

observable binding products. Different structures in the samples with gypsum and lime can be easily distinguished in **Figure 10b** to **Figure 10f**. In **Figure 10b**, needle like gypsum crystals are formed in plain earth with gypsum, forming a continuous web. The SEM images of G10 L2.5 and G10 L5 are given in **Figure 10c** and **10d**, respectively, which show fewer calcite crystals formed on the gypsum web and earth. SEM images of the samples taken from experimental buildings I and II are given in **Figures 10e** and **10f** showing a higher amount of calcite crystals formed and a denser structure in comparison to **Figure 10c** and **Figure 10d**. Continuing calcite formation over time also results in a denser structure for adobe with lime and gypsum. Finally, the pozzolanic reaction is also an important factor for forming a denser structure.

X-Ray Diffraction

X-ray diffraction was performed on all samples produced as part of the experimental study and the samples taken from two experimental buildings. The samples were taken 10 cm from the outer surface of the adobe wall in the experimental buildings. In this context, the quantities of gypsum, calcite, muscovite and SiO_2 are related to the materials used in the mixtures. XRD patterns are shown in **Figure 11**.

The XRD pattern of the plain earth sample in **Figure 11a** displays high amounts of muscovite and SiO_2, which can be present on a large scale in sand and earth. Gypsum and the compounds present in the plain earth sample were obtained in the analysis carried out on the adobe sample containing 10% gypsum, as shown in **Figure 11b**. The only difference between **Figure 11a** and b is gypsum crystals, as expected. Muscovite, SiO_2, gypsum and small calcite peaks were found in both the samples produced in the laboratory and taken from experimental buildings containing gypsum and lime, as shown in **Figure 11c,d,e,f**. Small calcite peaks were observed in the patterns obtained from the samples produced in the laboratory, as shown in **Figure 11c** and **11d**. The intensity of the calcite peaks were higher in the patterns of the samples taken from the experimental buildings. The intensity of gypsum peaks are quite different for the samples taken from experimental buildings I and II. This difference can be attributed to the different mix ratios of these two buildings.

Mechanical Tests

Compressive strength and modulus of elasticity

Compressive strength and modulus of elasticity tests were carried out on 10 x 20 cm cylindrical samples. The results are shown in **Figure 12** below. All series produced, except plain mix, exhibited parallel results during the first 7 days. Sample G10 with gypsum gained 0.37 MPa compressive strength at 1 hour, a significant part of its 7 day strength. Within the first hour, the compressive strength of the samples containing gypsum and gypsum with lime were satisfactory enough for the materials to be removed from the molds and transferred to the storage area. According to 1 hour test results, the compressive strengths of the samples with lime and gypsum (G10 L2.5, and G10 L5) were lower than that of the sample with only 10% gypsum. This result shows that the effect of lime on the rheology of fresh samples may be an important parameter. After 7 days, an induction period for compressive strength gaining started. All the samples gained the most significant part of their compressive strengths after 7 days. At the end of 90 days of curing in air, compressive strengths of the mixtures varied between 2.4 and 2.9 MPa. While plain samples had the lowest strength at all ages, the samples with 10% gypsum showed the highest strength.

Modulus of elasticity values of plain, G10, G10 L2.5 and G10 L5 samples were 880 MPa, 851 MPa, 831 MPa and 762 MPa respectively. It can be concluded that the magnitude of the modulus of elasticity was not influenced significantly by lime and gypsum addition to plain earth at the end of curing time.

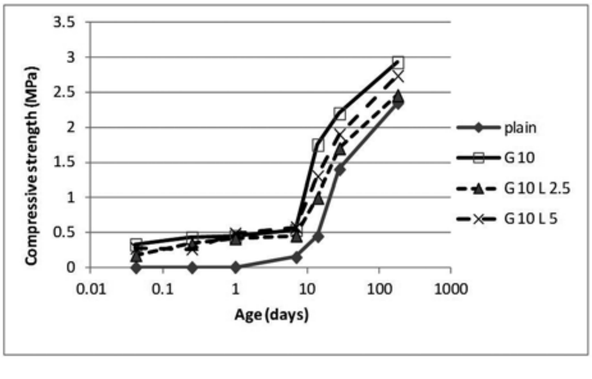


Figure 12. Compressive Strength.

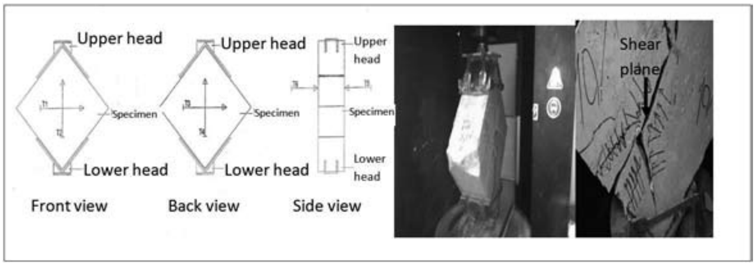


Figure 13. Shear Test System And Sample With Shear Failure.

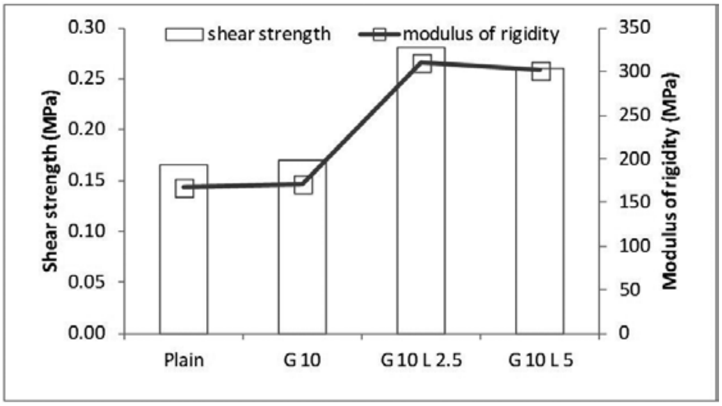


Figure 14. Shear Strength and Modulus of Rigidity.

Shear strength and modulus of rigidity

Shear strength tests were done according to the ASTM E519-10 standard. 50 x 50 x 20 cm block samples were used in the tests and loads were applied by a closed loop deformation controlled press with a capacity of 500 tons. A mold in 50 cm height was filled in three equal layers to produce the samples for shear strength test keeping inevitable joints in structure. A schematic drawing of the shear test system and a sample with shear failure are shown in **Figure 13**.

Shear strength and modulus of rigidity test results are shown in **Figure 14**. G10 L2.5 mix showed the highest shear strength and modulus of rigidity. There is not a significant difference between the samples having different amounts of lime. Shear strength and modulus of rigidity of plain samples and samples with gypsum are very close to each other. Dramatic difference on both values between the samples having and not having lime was obtained. The difference is in the magnitude of 50%. This result could be associated with pozzolanic reaction products and calcite crystals formed in the structure of adobe with lime addition.

The overall evaluation of test results was carried out in four main aspects as capillary absorption, shrinkage, microstructure and compressive strength.

Capillary water absorption increased with use of lime in the mixture. Although the capillary absorbed water level is lower in plain and G10 mixtures, they both were damaged from water underneath as part of the blocks tested were eroded and adobe at the cross section meeting with water dissolved. Considering resistance to water erosion, adobe building elements containing gypsum with lime would have longer life in comparison to plain and gypsum adobe. The water soluble gypsum web does not help against water erosion. Calcite crystals, which were formed due to carbonation of lime and binding products formed as a result of the pozzolanic reaction, were shaped around and over the gypsum web and earth particles in mixtures having lime. According to shrinkage measurement results, samples with both gypsum and lime exhibited the lowest shrinkage. The shrinkage values of the sample G10 L5, containing gypsum with lime, become closer to the magnitude of shrinkage values of cement based materials. This reduction in shrinkage of adobe stabilized with lime and gypsum limits the number of possible cracks due to shrinkage deformations and also minimizes the size of these cracks in the building. According to observations on experimental buildings, any shrinkage cracks which are commonly seen on the buildings constructed with adobe were not observed. The very low shrinkage amounts obtained can be attributed to needle like crystals formed which may resist compressive stresses due to shrinkage. The higher reduction in shrinkage values when lime is used may be a result of binding pozzolanic products and calcite crystals formed on the gypsum structure and earth particles.

Although the highest compressive strength was obtained in samples including only gypsum, dramatic differences were not observed between samples with or without lime. But significant differences of shear strength were obtained in the samples with and without lime. Considering the higher durability and shear performance of adobe with lime, this mixture can be suggested for practical applications. Considering that lateral earthquake loads have a higher impact on buildings and create a shear effect on the walls, an increase in shear strength and modulus of rigidity using gypsum with lime would have a positive effect on building performance.

Microstructural experimental study shows that the amount of pores in samples with lime is less than that of plain earth and earth gypsum samples. Although the height of water rises with capillary suction in samples with lime is greater, erosion resistance to water of these mixes is higher. Based on the principle that capillary water rises faster in narrower tubes, the capillary water absorption level increases in a short period of time in earth materials containing gypsum with lime due to the narrower capillary pores inside. MIP and SEM analysis results support this approach by lower pore volume values and a denser structure.

Even though examination of pozzolanic reaction products (C-S-H) was not in the scope of this experimental study, it is assumed that a reaction takes place between lime and silicious fine grains (Millogo et al., 2008).

Active (Ca^{++}) ions that are resolved from lime in water react with minerals in clay. This very slow but continuous chemical reaction creates a new water insoluble composition. This reaction, and the product formed as result, contribute to the development of increased mechanical performance and durability.

CONCLUSIONS

The conclusions obtained from this experimental study can be summarized as follows.

- Mechanical defects due to earthquake and durability problems such as flaking, wearing and collapsing were not determined on experimental buildings constructed with gypsum and lime stabilized earth built since 1984.
- Samples produced by adding 10% gypsum to plain earth reach 0.37 MPa compressive strength in one hour. Although addition of lime decreases

compressive strength slightly in one hour, the blocks have the capacity of carrying their own weight.

- Significant compressive strength was gained after 7 days for all series.
- Samples produced with addition of gypsum ad/or lime have higher compressive strength than plain earth.
- Samples with lime have significantly higher shear strength and modulus of rigidity than samples without lime.
- Addition of lime to earth mixtures provides resistance against water with calcite crystals and binding products of the pozzolanic reaction.
- Samples containing lime have finer pore structure.
- Shrinkage values decrease dramatically by using gypsum and lime in earth mixtures.
- According to the results obtained, adobe buildings produced with lime and gypsum (ALKER) can resist external factors and remain resistant to exterior conditions for years by means of the secondary structure formed in the earth mix.

APPLICATION RECOMMENDATIONS

Following the experimental and practical results obtained, the points that should be carefully handled in building adobe construction with gypsum-lime addition are as follows.

The particle size distribution of the soil must be carefully adjusted. Special care must be taken with the soil so that it contains a sufficient amount of fine grains as excessive clay will cause problems. Clay does not react chemically and binds large grains when exposed, increasing water sensitiveness and shrinkage. The other issue that should be carefully considered is that all of the prepared mixture should be placed into the mold before the setting time of gypsum. The setting time of gypsum is 8-12 minutes. Setting time of gypsum can be extended up to 20 – 25 minutes when using earth + lime + gypsum. This time period is satisfactory to mix, transport and place the mixture. A volumetric measurement should be made in order to make productive time management during production. The mix procedure on the construction site may be suggested as follows. The lime is added to the soil and mixed with water after reserving a sufficient amount of water to one side. The gypsum, stirred in a separate container, is added to the earth-lime mixture, remixed and placed into the mold. At the end of the placing process, it can be assumed that the setting of gypsum has been completed, the product has gained sufficient rigidity and it is ready to be removed from the mold and can be either stored in a warehouse or placed on the wall. Curing and other dry processes are not needed like other methods. The compaction process should be finished within the setting time of gypsum. At the end of this process, as the wall has gained sufficient rigidity to carry itself, the mold is removed and prepared for the next molding.

FURTHER STUDY

Experimental study should be planned in order to investigate freezing and thawing effects on samples containing lime-gypsum. C-S-H formation might be investigated experimentally; the petrographic and electronic-microscopic investigation currently carried on may contribute to the research of this aspect. Variation of setting time with lime and different earth types might also be determined. The mechanics of the prolonged setting time of gypsum within this particular mixture should be investigated. Behavior of existing or new buildings constructed with materials designed and experimented on in this study should be obtained under lateral and vertical loads. Shake table tests can be used in order to determine the behavior under lateral load. The results of these studies would lead to a proposal for determining sufficient wall thicknesses for different building sizes.

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ALÇI VE KİREÇ KATKISIYLA KERPİÇ YAPILARIN PERFORMANSINI YÜKSELTMEK

Dünyanın her köşesinde yoksulların konut sorunlarını çözmeyi amaçlayan çalışmalar yapılmaktadır. Bu kapsamda, yerel malzemeyle yapılabilen ucuz ve hızlı yapı sistemlerine her zaman gerek duyulmuştur. Alker adı verilen ürün de diğer katkılı yapı toprakları gibi, uygulanan bir stabilizasyon işlemi sonunda dokusu ve yapısı değiştirilerek fiziksel ve mekanik nitelikleri geliştirilmiş toprak kökenli bir duvar malzemesidir. Alker üretilirken toprağa alçı ve kireç katılır. Karışıma katılan alçı 20 dakika içinde prizini tamamlarken, kitleye kendi şeklini tutabilecek ve kilin rötresini önleyebilecek güçte rijitlik kazandırmaktadır. Bu makalede, 1980 yılında başlanmış olan, yapı malzemesi olarak kerpicin alçı ve kireçle stabilizasyonu projesinin devamı kapsamında yapılan iki adet deneme yapısından elde edilen sonuçlar aktarılırken, 2011 yılından itibaren yürütülmekte olan çalışma ile, üretilen Alker numuneleri üzerinde güncel standartlar ve yöntemler kullanılarak yapılan deney ve gözlemler sonucunda değerlendirmeler yapılmıştır. Ayrıca, yıllar önce yapılan deneme yapılarından numuneler laboratuvarda üretilen numuneler ile deneysel olarak karşılaştırılmıştır. Mikro yapı incelemeleri ile, alçı ve kireç katkılı Alker'in suya karşı dayanıklılığı ve düşük rötresinin nedenleri ortaya çıkarılmaya çalışılmıştır. Deneysel çalışma kapsamında katkısız, sadece alçı katkılı ve alçı-kireç katkılı numuneler üretilmiştir. Deneysel çalışmanın sonucunda; alçı ve alçı kireç katkılı numunelerin ilk bir saat içinde malzemenin kalıptan çıkarılmasını olanaklı kılacak dayanıma sahip olduğu anlaşılmıştır. Elde edilen erken dayanım, ilk yedi gün süresince numunenin rötre direncini artırırken, şekil ve biçim stabilitesinin korunmasını sağlamaktadır. Tüm alçı ve kireç katkılı numunelerin rötre değerleri, katkısız veya sadece alçı katkılı numunelerin rötre değerlerinden daha düşüktür. Zira, alçı kireç katkılı toprak malzeme ile yapılan deneme yapılarında da yıllar sonra yapılan gözlemlerde rötreye bağlı çatlaklara rastlanmamıştır. Alçı ve kireç katkılı numunelerin suya karşı dayanımının da, bu numunelerin içinde oluşan suda çözünmeyen yapıya bağlı olarak, sadece alçı katkılı veya katkısız numunelere göre daha yüksek olduğu belirlenmiştir. Alçı ve kireç katkılı numuneler ile sadece alçı katkılı veya katkısız numunelerin basınç dayanımları arasında dikkate değer bir fark tespit edilemezken, alçı ve kireç katkılı numunelerin kayma dayanımları ve rijitlik modüllerinin dikkate değer derecede yüksek olduğu belirlemiştir. Alçı ve kireç katkılı toprak malzemenin katkısız malzemeye göre üstünlüklerinin nedeninin genel olarak malzeme içinde şekillenen alçı ağ ve alçı ağ üzerinde ve arasında oluşan kalsit kristalleri ile C-S-H jellerinden kaynaklanabileceği sonucuna varılmıştır. Sonuç olarak, alçı ve kireç katkısı kullanılarak üretilen Alker toprak, numuneler ve söz konusu malzeme kullanılarak yapılan yapılar dikkate alındığında bu yapıların, malzeme içinde şekillenen ikincil oluşumlar sayesinde, uzun yıllar dış etkenlere karşı dayanıklı olduğu, rötreden meydana gelebilecek gerilmelerin yanında dış ortam etkileri sebebiyle yapıya zarar verebilecek hasarlara uğramadığı, geleneksel yargının tersine, herhangi bir bakıma gerek duymadan yıllar boyunca sağlam kalabildiği saptanmıştır. Bu konudaki laboratuvar çalışmaları devam etmektedir.

BEKİR YILMAZ PEKMEZCİ; BCE, MS, PhD.
Assistant Professor of civil engineering at İstanbul Technical University, where he graduated and received his PhD and MS degrees. His research interests include processing of cement-based materials, fiber-reinforced cement-based materials, materials for masonry structures.

RUHİ KAFESÇİOĞLU; Professor Emeritus
Is Emeritus Professor from İstanbul Technical University, Faculty of Arhitecture, where he earned Associate Professor degree in 1954 and Professorhsip in 1965. Established the Building Materials Laboratory at the same institution. Has numerous publications, particularly on earth construction buildings and earth as building material.

EBRAHIM AGAHZADEH; BS, MS
Received BS from Mahabad Azad University, İran and MS from İstanbul Technical University.