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# Gypsum-Stabilized Adobe (Alker) Structures: An Evaluation of Their Social, Economic and Environmental Advantages

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## ABSTRACT

*The advantages of traditional earthen structures in terms of their thermal properties and energy saving possibilities are well known. In view of the present radical increase in energy costs and exacerbating environmental problems, these properties become more significant. Furthermore, when constructed properly, their earthquake resistance is high. They are environmentally sustainable, and sufficient in terms of structural biology and bioclimatic comfort conditions.*

*ALKER, a mixture of adobe, lime, and gypsum, presents an important improvement over traditional earthen structures, as well as other means of adobe improvement. The mixture (gains rigidity) sets in around 20 minutes. Its shrinkage rate is lower than 1.5%. Its compression resistance is significantly higher than that of traditional adobe. In Alker, deformation and dimensional change during drying are very low; due to its molecular structure, it does not lose its properties when in contact with water; and it can be produced in any weather condition. Alker therefore provides significant energy conservation during production and use. Production process requires a minimal capital and infrastructure. Its environmental, and bioclimatic properties make it a contemporary building material suitable for a sustainable environment.*

## KEYWORDS

Earth structures, Stabilization, Alker, Economic advantages, Sustainable environment.

## 1 INTRODUCTION

Earth structures, which are the most common types of masonry structures in many regions of the world, have long fulfilled housing requirements of people. In our day too, large segments of the world's population live in earthen structures. This ratio may continue to rise in the future, since earth is the most suitable material for a sustainable environment, which can respond most satisfactorily to contemporary needs and requirements.

Earth structure is a structure type which can satisfy the needs of the wealthy in developed countries, where healthy and comfortable living are priorities, as well as the needs of the poor in developing countries. Since the benefits it provides can be developed further, and its disadvantages are repairable, and since social, economic and ecological problems gain increasing importance in the contemporary world, the use of earth as construction material has gained importance. For this reason, it continues to be a central subject of interest in research institutions of many countries.

In this paper, we will try to present the results of our work on Alker, which is a developed type of adobe, in addition to our thoughts on traditional earth structures. During research trips in those regions of Anatolia with very severe weather conditions, we have determined that in traditional structures, a mixture of earth, gypsum and lime was used as exterior coating material. The research of Prof. Postacıoğlu, whose details will be given in the following sections, were supportive and overlapping with this finding. In the experiments we have conducted with earth + gypsum + lime mixtures at the Istanbul Technical University Architecture Faculty's Construction

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Materials Laboratory, we have observed that a new product was created which is resistant to water and does not turn into to mud when in contact with water. Progressing our studies, with samples made with proper mixture ratios, we have obtained a material whose mechanical and physical properties satisfy contemporary requirements and which is resistant and stable. Further information on the material will be provided below.

## 2 BENEFITS AND DISADVANTAGES OF TRADITIONAL EARTH STRUCTURES FROM THE VIEWPOINT OF CONTEMPORARY LIVING AND COMFORT CONDITIONS

Traditional earth structures provide many benefits alongside their insufficient sides. Today's technology enables us to remove or mitigate deficiencies and improve the insufficient qualities with regard to structural technology and living conditions.

The advantages of traditional earth structures can be summarized as follows:

- This is a structure system which offers solutions to two important contemporary problems; energy saving and environmental pollution. Stack earth structures save energy during production and use, by decreasing fuel consumption to a minimum. They do not cause environmental pollution.
- They can be produced by the use of natural resources, with recourse to customs and traditions of the local communities.
- It decreases the energy consumption required for the production and transportation of wall material, which has the highest share both in volume and in weight in the construction of a building.
- It provides the best and healthiest bioclimatic comfort conditions without the need to have artificial installations and without energy consumption.
- During the use of the structure, the energy needed for heating is at minimum levels. This is significant for our country at a period when energy costs are very high. Comparative data on heating costs have been published in Kafescioğlu and Gürdal [1980].
- Earth structures enable benefiting from sunlight easily and at a maximum level due to its qualities of heat accumulation and the duration of heat transfer.
- Unlike other construction materials, the material used in earth structures does not require production capital for facility set-up, establishment and operating costs. Following the construction decision, after a short preparation period, work can commence.
- Housing, office and service buildings with contemporary standards and comfort levels can be constructed.

Earth buildings have some disadvantages besides these advantages.

- Earth structures, which are produced with traditional methods and used in their natural states are very sensitive to water and humidity. The mechanical and physical quality they gain through drying is lost when the water content reaches plastic viscosity.
- Natural earth material shrinks to a high degree while drying. This causes deformation and capillary fractures within the body. Fractures affect the properties of adobe to an important degree, and create a low-quality material that tends to crack up if the type of earth has not been selected well.
- In adobe produced by simple wooden castings, dimensional tolerance is high. During wall construction, this causes insufficient connections, unsmooth wall surfaces, plaster coating with uneven thickness that can be easily damaged, and an overall weakening of the structure.
- Adobe in its natural state breaks up easily and creates dust. Dust created in high amounts when insufficient structures are damaged causes life hazards.

In the following sections, we discuss in detail the proposed method that will largely eliminate these drawbacks, improve the physical and mechanical properties adobe possesses, enhance its inadequate aspects, in order to fully satisfy the needs of contemporary people.

## 3 ELIMINATION OF DRAWBACKS, IMPROVEMENT OF THE QUALITIES, AND ENSURING THEY ARE PERMANENT: STABILIZATION

Drawbacks and deficiencies of earth material can be eliminated to a high degree or be reduced to a minimum, and insufficient qualities can be improved through the use of contemporary technology. For this purpose, according to particular regional conditions, various methods are applied. These are easily available in the literature on the topic. Here we will explain in detail the findings related with our ongoing research project, and underline a number of points which we find important. We will shortly mention the principles that need to be considered for stabilization adobe. The type of earth to which stabilization methods will be applied and its granulometric structure are very important. Generally, the source for this subject is the ideal granulometry curve published in 1960s by the Arizona University Adobe Research Center.

As part of the TUBITAK MAG 505 Research Project on gypsum stabilized adobe, and during experiments conducted at different times at Istanbul Technical University Faculty of Architecture's Building Materials Laboratory, it was observed that as the granulometric structure of earth approaches the ideal curve, pressure resistance increased. Here, the upper limit of grain size is given as 20 mm. In the 'Second trial house' we have constructed through the TUBITAK INTAG TOKI 622 research project at the Ayazağa Campus we used earth whose appropriateness we had previously determined. We mixed the earth from nature, containing grains up to 50 mm, with gypsum and lime additives and poured the mixture into wall moldings of 30 x50 cm in width, and we have obtained satisfactory results. This mixture has also provided positive results in laboratory experiments. Thus, in structures where the in situ direct pouring method is applied, it was determined that coarse grains could be used provided that proper type of earth was found. The chemical composition of the earth and the appropriateness of the additive material which will be used in stabilization has to be tested. Generally, earth containing clays such as kaoline, montmorilolite, and illite are suitable for the application of different methods. Earth with marn which contains silt in high amounts does not form compounds suitable for combining with gypsum and lime. For such earth types, cement addition provides positive results. [R. Kafescioğlu et. al., 1980; Işık et. al. 1995, Işık and Tulbentci, 2008]

To be able to sufficiently explain the stabilization process and the mechanism that forms it, it will be useful to review the internal structure of the earth and its relationship with water. Since the study of the Swiss Professor Atterberg, the sizes of grains constituting earth are arranged like the following.

| Gravel | Sand | Silt | Clay | |
|---|---|---|---|---|
| 20.00 | 2.00 | 0.02 | 0.002 | Grain sizes mm |

When water is added to earth, it fills the void spaces between the grains; as water in the mixture increases, it goes between the grains and separates them. In adobe, silt and clay amounts are effective factors. Grains that have very small dimensions (0.02-0.002 mm) are high in number in the mixture; the sum of their surface areas is also very high. In water-earth mixtures, as the water ratio increases, water between the grains causes them to separate from each other. The product swells, its volume increases and it becomes pulpy. It changes from solid viscosity to plastic and liquid viscosity.

In the reverse case, if the body loses water, the water content in the body decreases, and the product is transformed from liquid viscosity to plastic viscosity; volume decreases and shrinking starts. It is possible to shape the product only when it is at plastic viscosity between liquid and plastic limits. As clay is a substance having cohesion and adhesion properties and plastic properties, it preserves the shape given at plastic viscosity. As it comes closer to liquid limit from plastic limit, shaping becomes more difficult and necessity of power usage arises. When no intervention takes place, it becomes rigid, dries and becomes half-solid viscous. This process continues until the clay particles touch each other. When the material reaches shrinkage limit, shrinkage ceases as water remains within the voids between particles; thus the material contains some amount of water. If the drying continues until the weight stays constant, the product becomes solid as the water in the body dries up (Table 1). Earth containing water, getting rigid or soft in relation to its water content is a reversible physical occurrence. The roughness the product gains after the physical process of drying is not permanent. When the product absorbs humidity and takes water into its body, the reverse situation develops. As we have just discussed, when the water content exceeds shrinkage value, swelling and decrease in resistance to pressure starts. When humidification exceeds plastic value, it looses its roughness and changes form and breaks up. Stabilization process has to be carried out in order to prevent deformation due to humidification, as well as to improve the product and to make its properties permanent.

Stabilization process can be gathered under three categories. The first is the correction of the granulometric structure and pressure application; the second is to provide a new chemical compound and crystal structure by developing new chemical reactions, and the third is to prevent the body from receiving water by rendering the clay particles impermeable. Based on these principles, various methods have been traditionally used, or experimented with depending on regional conditions. Among these are mechanical and chemical stabilizing methods, the most widely used being stabilization with cement. Lime, bitumen, and industrial wastes have also been experimented with as additives for stabilization of adobe.

As these issues have been widely published, here we will focus on the method we have developed using an adobe + lime + gypsum mixture.

### 3.1 Adobe Stabilized with Lime and Gypsum

In various regions of Anatolia with harsh climatic conditions, earth mixed with lime and gypsum has traditionally been used as an exterior coating material. During preliminary laboratory research, we have explored the possibility of using this mixture, highly resistant to harsh climatic conditions over long stretches of time. During the research project we have initiated in order to explore the possibility of using earth + lime + gypsum mixture widely for adobe production, we have obtained the positive results summarized below [Kafescioğlu et. al. 1980].

**Table 1.** Mix proportions for gypsum stabilized adobe

| Ingredient | % by weight |
|---|---|
| Soil | 100 |
| Gypsum | 10 % of soil weight |
| Lime | 2 % of soil weight |
| Water | 18-20 % of soil weight |

For types of earth suitable for adobe production, the gypsum + lime additive is a satisfactory stabilization method. At the end of this process, a product possessing sufficient mechanical, physical and economical qualities is obtained. Furthermore, the product is satisfactory in terms of structural biology, structural geology and the creation of desirable bioclimatic conditions. Values reached during laboratory research were tested at four different trial buildings, and the estimated results were obtained. In the following section, we will try to define the properties of gypsum added adobe, which we have called ALKER, in some detail.

**Table 2.** Physical Properties of Alker

| | |
|---|---|
| Unit weight | 1.6-1.7 kg/lt kg/l |
| Shrinkage | 1.0-1.5% |
| Compressive strength | 2.0-4.0 N/mm2 N/mm$^2$ |
| (Sheer ) Shear strength | 0.9-1.3 N/mm2 N/mm$^2$ |
| Water absorbtion | very low |
| Heat transfer value | 0.4-0.5 kcal/mhC |
| Specific calorific | 1.0 kJ/kgK |

Alker, which is obtained as a result of gypsum + lime addition to adobe gains the following properties in comparison to compounds where other additive materials are used.

- In the normal drying process of clay, the gypsum completes it setting in a short time, and before shrinkage starts. This causes an internal structure which prevents or radically reduces shrinkage levels. The material gains rigidity quick enough to be taken from the mould and stacked. While shrinkage in normal clay is around 20%, in Alker, it is around 1%.
- Earth + gypsum + lime mixture completes its setting in approximately twenty minutes. This is enough time for the mixture to be prepared and placed in moulds. As the product can be taken from the molding quickly, there is no need for drying and cure processing like in the other methods.
- Since there is no need for spreading out the material for drying or cure, production can be maintained under a lean-to-roof without the product being affected by rain or other climatic events.

## 4 DEFINITION OF ALKER, ITS BODY STRUCTURE AND PROPERTIES

Alker is a modified version of the mixtures prepared with earth for structure. This mixture may be produced as adobe blocks or the mixture can be directly filled and compressed in wall moldings. According to the preliminary findings of the research project that has not yet been finalized, the mixture can directly be filled into molding with a pump after determining that is has the proper granulometric structure and viscosity. In this case, the cost will decrease a little as the pouring process will be easier and there will not be any need for compression.

Alker, in other words, is an earth-based building material whose properties have been visibly improved. The new body and crystal structure formed by the combination of the clay minerals with free calcium ions released during the setting of lime and gypsum, has the following set of properties in comparison to similar modified earth products.

- We can explain the formation mechanism of Alker as following: the clay and lime content of the mixture lengthens the setting time from 8-10 minutes up to 20 minutes. Within this time the gypsum completes it setting, and forms a homogeneously formed web tissue within the body, which has the strength to counter the internal dynamics that work towards shrinkage. This tissue prevents the material from shrinkage, prevents the volumetric decrease, and enables the body to be more porous.

**Table 3.** Unit weight change according to gypsum / earth ratio of different earth types containing clays such as kaolinite, montmorilolite, and illite

| Dry earth/gypsum ratio | 0.00 | 0.10 | 0.15 | 0.20 |
|---|---|---|---|---|
| Porosity | 0.39 | 0.42 | 0.43 | 0.44 |

- As the body of Alker is more porous, its unit weight (1.4-1.5 kg/dm$^{3)}$ is a little lower with respect to other adobe types (typical value 2.2 kg/ dm$^3$). In types of earth whose granulometric structure is suitable for adobe production, shrinkage approaches zero, and the unit weight decreases considerably as the gypsum additive ratio increases. Curves 5 and 6 in figure 2 are samples with suitable clay types and granulometric structures that are close to the ideal curve. Here, the effect of gypsum additive is clearly seen.

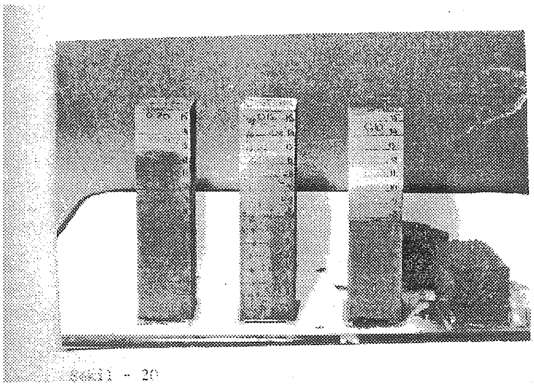

**Figure 1.** Porosity and resistance to water of earth suitable for adobe production; plain and gypsum added samples with 10, 15, and 20 % ratio. The plain sample dissolves 4.5 hours later whereas the gypsum added samples preserve their integrity 24 hours later. In samples with high amounts of gypsum additive, the water level rises faster. Although the body absorbs more water and the water level exceeds the shrinkage limit, the sample preserves its integrity.

- In types of earth which are suitable for adobe production, although the body becomes more porous as the gypsum ratio increases, mechanical properties reach higher values when compared to the other adobe types. Pressure resistance increases depending on the gypsum ratio. In types of earth with suitable granulometric structure, pressure resistance is higher below [R. Kafescioğlu, *et. al.* 1980, p. 73 fig. 27]. This is also one of the topics to be investigated during the new research project to be mentioned.
- Alker's improved mechanical properties may be due to the fact that its shrinkage levels are lower than other types, and that it gains sufficient rigidity by completing its setting in a short time. Hence no deformation or capillary fractures occur.
- The new chemical compound and crystalline structure formed by lime and gypsum creates a new material whose sensitivity to water is reduced to a minimum level. The new material preserves its integrity without breaking up in the water for a long time (fig. 1). In the picture, rising of water in relation to time and distributions of plain samples with dimensions 4/4/16, and the behavior of gypsum added samples at a ratio of 10, 15, and 20 % are shown. The plain sample dissolves completely in 4.5 hours. In samples with additives, although the water rises within the body as the gypsum ratio increases, the material preserves its structural integrity. Tensile stress at bending and pressure resistance of Alker is higher when compared to other types of adobe. These properties enable Alker buildings to have higher degree of earthquake resistance. One of the questions the new research project focuses on is the mechanism through which a new chemical compound is formed, and its crystalline structure.

- Energy consumed during the production process of Alker is limited to the energy consumed for the production of gypsum and lime to be added to the material. Therefore energy consumption is significantly lower when compared to use of cement as stabilizing material. The energy amount consumed for production of clay brick in a factory is around 7000 kCal/kg. Energy consumed for the production of Alker is close is minimal.
- Its heat accumulation capacity, its heat transfer time, are factors which provide considerable energy saving in heating and air conditioning [Kafescioğlu 1987]. (See Table 2)
- It is a beneficial solution from the point of view of one of the most significant problems of our day, environmental pollution, since it radically decreases fuel consumption.
- Time, labor, or capital needed for the construction of a facility is minimal.

## 5 PROPERTIES OF ALKER STRUCTURES, BENEFITS THEY PROVIDE, AND USAGE OPPORTUNITIES

- Buildings constructed with Alker provide high energy savings with regard to indoor climatization. Instead of the concrete bricks widely used in rural areas, earth structures whose properties are improved provide significant personal and communal benefits in terms of economy and health.
- These properties at the same time enable the indoor bioclimatic comfort level to be minimally affected by outside climatic changes.
- Alker structures satisfy contemporary requirements in terms of structure economics, structure biology, ecology, thermal comfort and environmental pollution control. From this point of view, they can be labeled as proper structures for a sustainable environment.
- Main structural failures of earth structures in terms of earthquake resistance are due to use of low quality adobe, insufficient wall construction, improper arrangement of lintels, and big differences in brick sizes. Experiments and measurements performed with Alker wall samples have provided positive results on this subject [Kafescioğlu, 1985; Işık et. al. 1999].
- To be able to obtain more precise information in this regard, we have to wait for the results of full scale seismic simulation tests to be completed in the near future.
- As Alker buildings are produced completely with natural material, they are healthy structures in terms of structural biology, providing bioclimatic comfort conditions in every region of Turkey. During experiments and measurements conducted by the structural biologist M. Arch and Akman at the first trial house, these properties are have been explored. In a comparative study of two pre-school units built with Alker and reinforced concrete respectively, the Alker building has proven to provide significantly higher bioclimatic comfort conditions [Akman 1997, Akman 2005].
- As seen in the section on methods of construction, Alker is easy to produce in diverse regions and climates. Since the production and construction process is based on traditional methods, Alker structures can be produced in short stretches of time. This is especially significant in providing permanent, healthy, and comfortable housing after natural disasters such as earthquakes.

### 5.1 Possible Uses of Alker Structures

In underdeveloped countries and regions, earth structures, especially built with an improved type of adobe such as Alker, present beneficial examples, since it is possible to construct high quality buildings in large numbers at low costs.

- In developing countries and new areas of inhabitation, efforts towards the improvement of traditional earth construction technology can easily be implemented. Local communities can contribute to the construction effort in significant ways, and people can build for themselves higher quality housing.
- Alker and joinery production facilities to be constructed in disaster regions in a very short time and with little cost, for the construction of permanent, healthy housing.
- For buildings used in agricultural sectors in rural areas, and particularly for poultry farms where temperature control is important, Alker provides significant benefits and savings.
- Since the wall building material, which constitutes the largest component in volume and weight of construction, is available in the immediate surroundings of the construction site, transportation costs can be minimized.
- The method of placing the mixture into the molding by pulverizing provides benefits as the construction time and cost are decreased, and the quality of the product is improved.

## 6 METHODS OF CONSTRUCTION WITH ALKER, AND TRIAL BUILDINGS

Two different methods can be used in constructing with Alker. General construction rules and methods for shaped block material in structural masonry are applicable to Alker. The tensile strength of Alker blocks at pressure and buckling are higher than required levels (table 2). Its porous body does not deform with humidity and is not affected by contact with water; it provides important energy savings during production and use; and meets contemporary requirements in terms of structural biology and ecology, and has the properties of masonry construction.

The in-situ construction method used in concrete structures can be applied to the Alker mixture as well. Here the important point that should be taken into consideration is that the preparation of the mixture, placing it into the mould, shaping and compression has to be completed in 20 minutes, the setting time of the mixture. Compression after the setting time is reached will result in dissolution and breaking up of the material. The mixture prepared for this purpose can be poured into the molding and compressed with a compactor, or the mixture can be pulverized into the molding directly with a pump, as is done with ready mixed concrete. Although the experiments conducted for this method have not been finalized yet, positive results have been obtained in preparatory studies. The mud with the proper viscosity and granulometric structure will not require a further compression process after being pulverized to the moulding. Therefore this method will have lower costs, and there will not be a setting time risk. It has been observed that the method used for adobe-cement mixtures, whereby the wall is constructed by pulverizing the material to a single side moulding, can not be applied to Alker, since trimming operations can not be carried out once the setting process is complete.

Four trial buildings have been constructed with Alker between 1983 and 2000. In the first trial house initial laboratory results have been applied on site, with positive results. For the duration of a year, experiments have been carried out regarding structural biology, and energy consumption and savings. In the second trial house, possibilities for serial production and in situ pouring in moulds have been explored, with earth taken directly from the site. The third trial house is a 240 m2 building constructed for a private patron, and inhabited throughout the year. The fourth trial building is located in the South Eastern Anatolia development project area (GAP), and is a two story housing compound for employees [Işık 2000].

## 7 NEW RESEARCH ON ALKER AND EXPECTATIONS

Work on Alker continues with a new research project. In earlier experiments, earth proper for adobe production, containing 20-25% clay and silt was used. In recent experiments, with earth containing over 70% clay and silt, we have obtained samples in the color and appearance of brick, whose pressure resistance is high. Experiments were conducted with samples of 7x7x7 cm dimensions, produced with a new mixture obtained by the addition of aggregate in various ratios and improved granulometric structure (we have kept the 10% gypsum ratio, and added 2.5, 5, and 7,5 % lime). In recent experiments, we have reached higher pressure resistance values (fig. 2). These results have led to further research on the topic. In preliminary studies, during pressure tests performed with 7/7/7 cube samples, the samples demonstrating resistance up to 27 KN, break in the form of two reverse pyramids, that is, the breaking pattern not of unbaked brick (which tends to crumble), but of building material with a higher pressure resistance such as concrete or baked brick (fig. 3). This is important, as it shows the possibility to produce a material similar to brick without the baking process. During precipitation experiments, one of the plain samples dissolved completely. The second sample was greatly damaged, while the gypsum added samples exhibited damage between 0 and 2 % (figs. 4, 5).

A comprehensive research programme to explore the properties of the newly formed crystalline structure and the new chemical compound which is formed during the setting of lime and gypsum with clay, through the releasing of the free Ca (calcium) with ions will begin with the collaboration of the department of Chemistry. Through this project, in addition to the in-depth study of the chemical properties of the material, a comprehensive study will be conducted including earthquake assessments, energy economy, structural biology, and structural ecology.

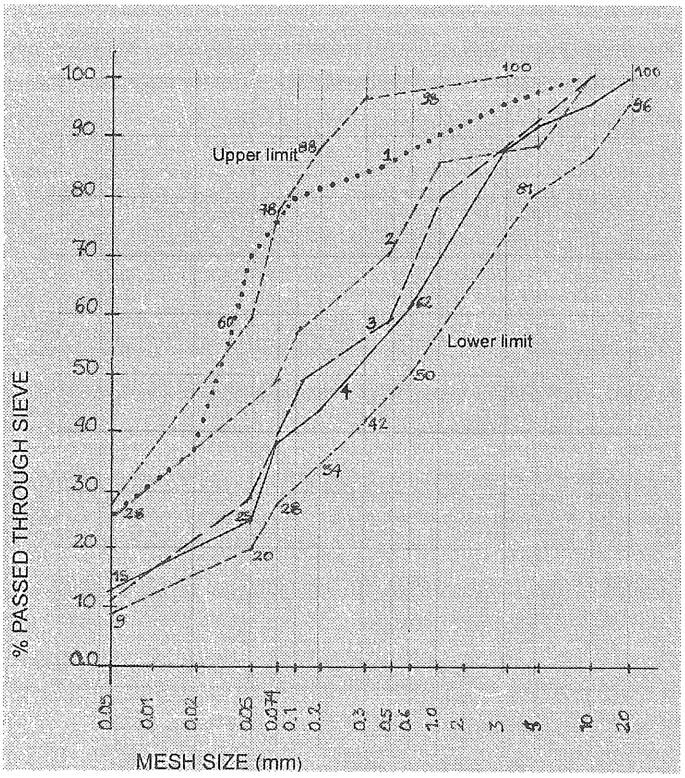


**Figure 2.** Granulometric curves of plain and aggregate added clays.

1. All-in aggregate soil used in the second trial house
2. 70% all-in aggregate
   15 % 0.05 – 0.10 cm aggregate
   15 % 0.10 – 0.20 aggregate
3. 60 % all-in aggregate soil
   20 % 0.05 – 0.10 cm aggregate
   20 % 0.10 – 0.20 cm aggregate
4. Ideal granulometric curve of earth to be used for unbaked brick (Arizona University Adobe Research Center)

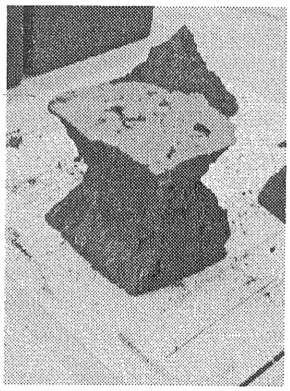

**Figure 3.** Showing the failure of the sample in compression.

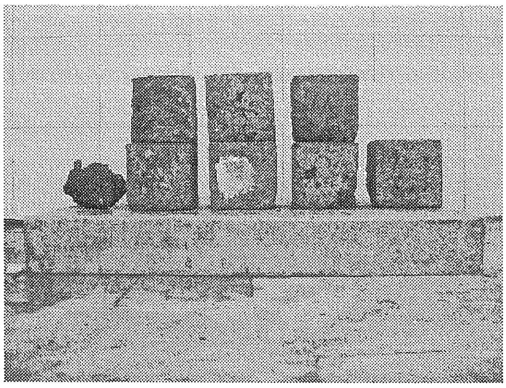

**Figure 4.** The samples prior to precipitation experiment**Figure 5.** The samples after the precipitation experiment

## 8 DIRECTIONS FOR FURTHER RESEARCH

After the properties of the new compound and the crystalline structure are determined, the possibility of binding with higher amount of the clay as far as possible in the mixture, and accelerating the formation will be explored. Further possibilities of shaping with moldings will be explored by adjusting proper viscosity. It this proves possible, the production of blocks with voids, and plates will be experimented upon. This paper presents the results of previously completed research on the topic. The results obtained on gypsum stabilized adobe until the symposium date will also be presented to the conference participants, to be opened to discussion.

## REFERENCES

Akman, A., 1997, "Baubiologischer Vergleich zweier Kindergärten" *Institut für Baubiologie + Oekologie Neubeuern IBN — Zeitschrift W+G,* 16-17.

Akman, A., 2005, "Building biology and one bioclimatic – diagnostic examination," Proceedings, Living in Earthen Cities – Kerpic'05" page 212-219, Istanbul Technical University, Istanbul.

Işık, B., Akın, A., Kuş, H., Çetiner, İ., Göçer, C., Arıoğlu, N., 1995, "Mechanization of Gypsum Stabilized Earthen Construction Technology," Research project 622, TUBITAK INTAG TOKI.

Işık, B., 2000, *Alker Yapılar 1983-2000*. İstanbul.

Işık, B., Tulbentci, T., 2008, "Sustainable housing in island conditions using Alker, gypsum-stabilized earth: A case study from northern Cyprus," *Building and Environment,* 43, 1426-1432.

Kafescioğlu, R., Toydemir, N, Gürdal, E. Özüer, B., 1980, *Yapı Malzemesi Olarak Kerpicin Alçı ile Stabilisazyonu* (Gypsum Stabilized Adobe as Construction Material), Istanbul; Research project MAG 505 supported by TUBITAK (Turkish Scientific and Technical Research Institute.

Kafescioglu, R, and Gürdal, E. 1980, *Çağdaş Yapı Malzemesi: Alker*, Istanbul.

Kafescioglu, R, 1987, "Thermal Properties of Mudbricks," Amman Expert Group Meeting on Energy-Efficient Building Materials for Low-Cost Housing. Amman.