Effect of Gypsum Stabilization on Mechanical Properties of Compressed Earth Blocks

Maher O. Amin, Lecturer
Department of Buildings -Technical Institute of Mosul

Abstract

There is a need for development of alternative materials for the building industry with low carbon footprint and at the same time saving energy. Clay has been used as a building material from the beginning of humankind. The Compressed Earth Blocks often referred to simply as CEB, is a type of manufactured construction material formed by the compression of the soil in a mould with the help of a manual or motorized press to form a regular block of appropriate shape and size. For the purpose of researches the press is manufactured locally at Mosul Technical Institute. In the present work, the effect of semi-hydrate gypsum as stabilizer on some of the mechanical and physical properties of unfired CEB was determined. A series of test blocks were fabricated using a local soil stabilized with 0, 5, 10, 15, 20 and 25% semi-hydrate gypsum, for each of the precedent ratios, three percentages of mixing water was used 10, 20 and 30%, and compacted with a manual press. Results for compressive strength, flexural strength, water absorption and drying shrinkage are presented in the paper. Results show that the addition of semi-hydrate gypsum improves the mechanical and physical properties of CEB. These preliminary results reinforce their suitability for application in low cost buildings.

Keywords: CEB, Stabilization, Semi-hydrate gypsum, Mechanical behaviors

تأثير الجص كمادة مثبتة على الخواص الميكانيكية لكتل التربة المضغوطة وغير المفخورة

الخلاصة

هناك حاجة ملحة لاستخدام مواد بناء جديدة اقتصادية في استخدام الطاقة وصديقة للبيئة. إن التربة قد استخدمت في البناء منذ أقدم الازمنة. في هذا البحث محاولة لتحسين صفات كتل البناء المصنعة من التربة باستخدام الضغط وإضافة الجص لتقوية كتل التربة، استخدمت ماكنة كبس تعمل يدوياً لكبس التربة داخل قوالب حديدية تسلط ضغط كبير جداً وتسمى CINVA-Ram معروفة عالمياً، وقد تم تصنيع هذا المكبس محلياً وبنجاح في المعهد التقني–الموصل وقد استخدم لإنتاج كتل التربة التي استخدمت في هذه الدراسة. في هذا البحث تم دراسة تأثير إضافة الجص إلى التربة المحلية بعدة نسب تراوحت بين الصفر و 25% بزيادة تدريجية 5% وكذلك تأثير تغيير نسب ماء المزج إلى مزيج التربة والجص للخلطات السابقة بمقدار 10 و 20 و 30%. أظهرت الفحوص إمكانية استخدام هذه الكتل البنائية الجديدة في الابنية ذات الكلف الاقتصادية المنخفضة.

الكلمات الدالة: كتل التربة المضغوطة، تثبيت التربة، الجص، الخواص الميكانيكية

Introduction

Over the past 40 to 50 years, there has been an increasing interest in the use of stabilized compressed earth blocks for residential construction[1-10]. They maximize the use of locally available materials; require relatively simple construction methods, whilst offering favourable thermal and acoustic insulation properties. Environmental benefits include reduced energy consumption in production and a lessening demand for non-renewable resources[1]. Earth building is not a characteristic only of the Third World. Earth walled houses can be found in France, Germany, New Zealand and in some regions of Australia about 20% of the houses are built with walls of unfired earth. In western countries, thousands of luxury earth homes have been built in the last few decades [7]. These have showed the feasibility of this material as a natural building material. The strategy will have the potential to reduce costs, conserve energy, and minimize waste. On the other hand, unfired clay materials provide a sustainable and healthy alternative as a replacement to conventional masonry materials [6]. Unfired clay soil bricks have been a traditional construction material especially in rural regions; it can be reused easily without affecting the environment by means of grinding and wetting or returned to the ground. However, the main deficiency of unstabilized clay soil is its susceptibility to water damage. This problem is now over by stabilizing the clay soil with the addition of a small amount of cement, lime, gypsum or fly ash thereby enhancing many of the engineering properties of the soil and producing an improved construction material[9].

Descriptions on the gypsum-stabilized earth (GSE) can be found on the websites of [3] and [8]. They provide basic information such as the amount of gypsum needed for proper stabilization together with quantities of clay and sand. Vroomen[5] point out the advantages of gypsum-stabilized earth (GSE) construction, on basis of a qualitative comparison between adobe construction, gypsum-stabilized earth (GSE) and concrete construction. He concludes that material cost is low, its durability is medium, the emission of CO_2 is null, and the energy required for the production is low [7]. In the work of Vroomen[5] it is indicated that 10% of gypsum is a good quantity to obtain appropriate compressive strength. In addition, it is suggested that gypsum-stabilized earth can potentially decrease the housing construction costs of low income groups Lowenhaupt[3]. Vroomen[5] also he Suggests a qualitative comparison between: adobe, gypsum-stabilized earth (GSE) and concrete construction, which place the GSE at the middle of them, for instance the material cost is low, the durability is medium and the energy required is low while CO_2 production is null.

One of the more modern additions to the earth building scene is to make compressed earth bricks in manually or engine-operated presses. The compression given by the machine compacts the soil particles together to make dense regular shaped bricks, usually around 300 x 140 x 110mm in size. Most presses will enable some variety of shapes.

Materials and Mixture Design

Materials

The materials used in the investigation were local available soil taken from location outside of Mosul city which is chiefly of clay and silty soil, commercially available semi-hydrate gypsum ($CaSO_4 \cdot 1/2H_2O$) were used as stabilizer and supply water for human consumption. The various physical properties of the soil used for the investigation are summarized in Table(3). However, the proportions of various kinds of material which are recommended for the manufacture of compressed earth blocks are shown in Table(2), it is apparent that our soil is not suitable for making compressed earth blocks, however, this soil was attempted and only gypsum stabilization was tried in this research without altering the grain size characteristics. Soil-gypsum blocks of size: 290×140×100 mm was used in this investigation. Manually operated block making machine was employed to produce these blocks.

Samples preparation and Mixture design

The "qualified" soil is dried by spreading it in an open space, larger granules of soil, such as lumps and gravel are removed by sieving with 6 mm sieve; required quantity of soil was weighted. The levels of gypsum used in the various mixtures investigated were respectively 0, 5, 10, 15, 20 and 25% by weight of semi dry soil. Three ratios of water contents were used for each of the above soil-gypsum mixes, 10, 20 and 30%. The mixing was done by small concrete mixer and continued sufficient time to get a homogeneous mixture of constituents. The soil-gypsum mix was then transferred to a CINVA-Ram press for molding. The ejected blocks, see Fig.4, were then placed in a yard and wrapped tightly with plastic cover to preserve the moisture for three days and then damp cured for the maturity about two weeks. After one month the blocks weighed separately in order to calculate the block density. Finally, the blocks were tested for compressive strength, flexural strength, shrinkage and absorption. Four specimens for each mix were tested for compressive strength and two specimens for flexural strength.

Testing Procedure

Compressive strength and modulus of rupture (flexural test)

Universal testing machine, Fig.7 was used to carry out the compressive and flexural tests. The compressive strength and modulus of rupture (flexural strength) was determined in accordance to the standard ASTM C67. The modulus of rupture of each specimen was calculated by using the following formula:

$$fr = 3PL/2bd^2 \quad \text{.........................(1)}$$

Where:

fr = modulus of rupture of the specimen at the plane of failure, MPa,
P = mid-span concentrated load indicated by the testing machine,
L = distance between the supports, mm,
b = net width of the specimen at the plane of failure, mm,
d = depth of the specimen at the plane of failure, mm.

The compressive strength in MPa was calculated by dividing the breaking load (maximum load) in Newton's by the average of the gross areas of the upper and lower bearing surfaces of the specimen in square millimeters.

Water absorption

Water absorption of brick samples was measured, see Fig.8. The test method to determine the quantity of water absorbed in 24 hrs was as follows: After immersing the specimens in water at room temperature for 24 hrs, then remove the specimens from the water and allow it to drain for 1 min by placing them on a wire mesh, removing visible surface water with a damp cloth; weigh and record as Ws (saturated weight). Then, dry all specimens in a ventilated oven at 105 °C for not less than 24 hrs and two successive weightings at intervals of 2hrs showing an increment of loss not greater than 0.2% of the last previously determined weight of the specimen. By recording the weight of dried specimens as W_d (oven-dry weight). The water absorption is calculated by using the following equation:

Absorption (%) = $[(W_s-W_d)/W_d)] \times 100$ ………. (2)

Water content

The water content more convenient for molding the bricks is also function of the soil type. To obtain compressed bricks of quality with a certain earth, it is necessary to establish the ideal percentage of water and amount of material to be put in the mold of the press, through an optimization process. The water content is not usually the same obtained by the Proctor test where the maximum density is reached by a dynamic compaction. In the press, the compaction is almost static, what gives a certain difference. In the preparation of specimens we used the aforementioned percentages, ignoring the optimum deliberately.

Shrinkage

The dimensions of the bricks were measured after three months, see Fig.6, usually very little moisture is required to produce a CEB, and so the blocks do not shrink and crack, however large shrinkage noted for the 20% and 30% of mix water, increased proportionally with mix water, shrinkage during drying depends on the mixture's water content, the type of clay and percentage of clay, and the distribution of grain size of the structural filler.

Results and Discussion

Characteristics of CEBs stabilized with semi-hydrated gypsum with five different gypsum contents (5, 10, 15, 20 and 25%) are examined. Characteristics of compressive strength, flexural strength, shrinkage and water absorption of CEBs were determined by the procedure explained in the previous sections. The results of these characteristics are discussed. From Figs1, It can be observed how the compressed soil bricks stabilized with gypsum show better compressive strength than that with no or low stabilization with gypsum. This improvement can be attributed to the crystal formation between soil and gypsum. Similar effect on flexural strength can be shown from Fig.2. The effect of mixing water on shrinkage was very noticeable from Fig.3, also from Fig.4. Water absorption and shrinkage decreased significantly with increasing gypsum/soil ratio.

Conclusions

The mechanical and physical properties of CEBs made of clay-gypsum were determined. The following main conclusions can be drawn from this study:

1. The flexural and compressive strength of the CEBs were improved by the presence of gypsum.
2. Too low or too high mixing water result CEBs with low compressive strength.
3. There is a direct proportional relation between the amounts of gypsum as stabilizer and compressive strength, but this amount would be governed with the economical factor. In general, these preliminary results are thought to be adequate to reinforce their suitability for application in low cost building bricks as well as to score on the energy conservation scale.

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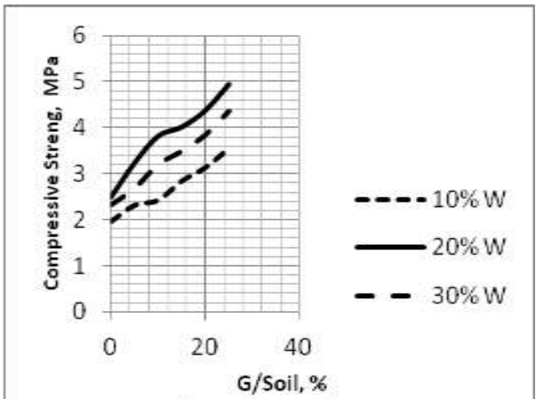

Fig1 Effect of Water&Gypsum on Compressive Strength

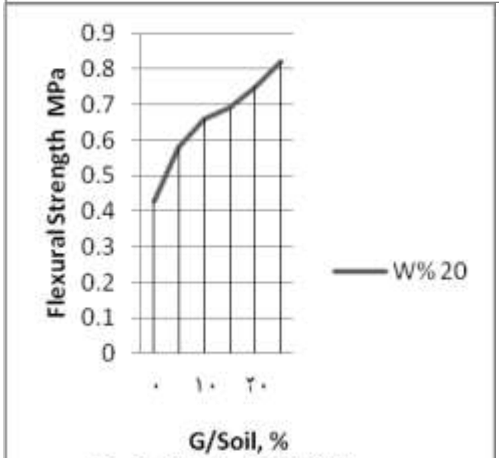

Fig.2 Effect of G/Soil % on Flexural Strength

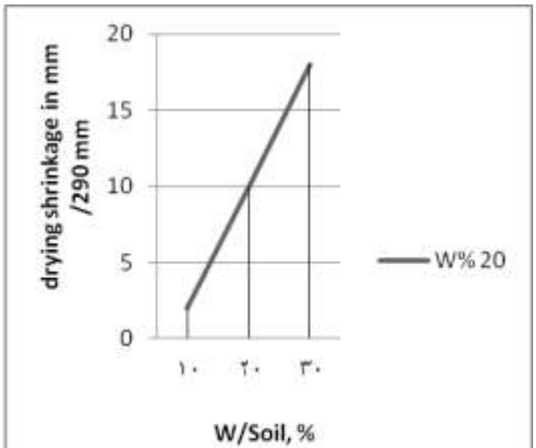

Fig.3 Effect of Mixing water on Shrinkage

Fig.8 After absorption test used in this work

Fig.5 Demoulding of CEB from the CINVA-press

Fig.6 Effect of Mixing water on shrinkage

Fig.7 Flexural test used in this work

Fig.8 After absorption test used in this work

Table (1): Typical temperatures of production

Portland cement	1450-1550 °C
Lime	800-900 °C
Ceramic bricks	800-1000 °C
Steel	1600-1800 °C
Gypsum	120-180 °C

Table (2): Grain size distribution recommended by manufacturers,%

Gravels	0-40
Sands	25-80
Silts	10-25
Clays	8-30

Table (3): Physical properties of soil used

Grain size distribution	
Gravel, %	0.0
Sand, %	5.20
Silt, %	51.30
Clay, %	43.50
Atterberg's Limits	
Liquid limit, %	32.72
Plastic limit, %	22.84
Plasticity index, %	9.88
Classification : CS Clayey Silt	
Optimum Moisture Content, %	19.00
Maximum dry density, gm/cm³	1.65

Table (4): Influence of G/S % on water absorption, mixing water 20 %

G/Soil %	Absorption %
0	6.4
5	6.1
10	5.9
15	5.6
20	5.2
25	5.2