Production of Earth Units Compressed and Stabilized by Using Cement and Pozzolana

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Abstract. Earth units compressed and stabilized are friendly construction materials and sustainable from point of view of efficiency in using energy and lowering cost. However, it has lower properties and strength when compared with fired clay brick and concrete. The possibility of producing earth units compressed from soil stabilized with cement and pozzolana were investigated in this study. Soil samples were extracted from a pit at depth 1m under topsoil from Al-Zaafarania region in Baghdad. Results of the testing soils showed that the bulk density, moisture content, specific gravity and plasticity index performed satisfactory and suitable to produce such like soil units. Different percentage of cement and silica fume as a stabilizer. Soil units compressed with 20 N/mm² pressed by a hydraulic loading machine. The unit’s strength significantly increase with increasing silica fumes content, decreasing the absorption water rate, and raises density of units.

1. Introduction

The earth compressed stabilized units are an addition to recent technology of clay brick producing, blocks, and road pavement units. Earth used in many ways in the construction of walls. However, earth has few undesirable properties like weak dimensional stability, poor performance due to water saturation, and driving rain or wind caused erosion. To significantly eliminate the previous drawbacks, the soil can be stabilized with a chemical material like cement [1].

According to Krosnowski [2], there are environmental sustainability and economic benefits for manufacturing and building with compressed stabilized brick. The prime benefit is that it uses local materials and minimizes transportation costs since it is in-situ producing, healthier homes production since it is nontoxic and can renewable. Other benefits include higher production and needs lower labor skills. Moreover, better sound resistance and good durability and flexibility in use more than the adobe blocks if maintain the compaction uniformly.

The manufacturing process involves eight stages including sifting the soil, weighing, mixing, observing moisture content, casting, compressing the mixture in a mold, quality control, wet curing and stacking [3].
Briefly, the compressed stabilized blocks are manufactured by slightly moistening the combination of soil and stabilizer, then cast the mixture in a steel mold and applied the required compression on the mixture whether manually or mechanically. Compressed earth block with or without stabilizer can be performed to different sizes and shapes. For example, the Auram press 3000 suggests 18 kinds of molds to produce practically 70 blocks type. These types are shown in Figure 1.

![Figure 1. compressed stabilized earth blocks by the Auram press 3000.](image)

Cement is one of the stabilizing materials that widely used where it reduces the liquid limit, increases the plastic limit, and enhances soil workability. Moreover, cement fastens the sintering process and enhances the chemical reaction which depends on the type of used stabilizer [4]. Sufficiently increment occurs in water resistance, compressive strength, and stabilization in dimensions when using cement as stabilizer ranging between (4-10)% for producing compressed stabilized earth units. In addition providing acceptable thermal and acoustic insulation characteristics [5]. With cement stabilization, the blocks must be cured for four weeks after manufacturing. One of the functions for the stabilizer is to reduce the soil swelling through creating a solid and cohesive structure with the earth mass, in addition to improve the bearing and durability of soil [6].

Stabilizing soil according to [7] is a change or modifies any property to improve its engineering performance. The factors that affect stabilizing are soil type, amount of stabilized used, the pressure applied in production, and the most important factor was the method of mixing soil with stabilizer. Fetra et al [8] refer to that the soil with plastic limit less than 15% was suitable to use stabilized with cement and proved the possibility of using stabilizing with cement higher than 10% but that will be economically inefficient. Although, Mesbah et al [9] mentioned that the stabilized with cement must be ranging between (4-10) % by weight of dry soil.

Many stabilizers can be used. Cement and lime are the most common ones. Others, like chemicals, resins or natural products can be used as well. Asgari et al [10] proved that cement stabilization increased the unconfined compressive strength of the soil significantly and in general improvement in mechanical properties is higher compared to lime stabilization. The compressive strength of soil with lime stabilization is more dependent on time rather than dosage; hence it gains strength with time [11]. Soil with moderate plasticity index almost always has higher compressive strength than that of lime stabilizer, however for soil with high plasticity index, the lime stabilizer is more superior [11]. Even though cement is a good stabilizer, it is energy-consuming, costly, and environmentally unfriendly [12]. Thus, it is better to combine with pozzolana and other byproduct mineral materials so as to reduce cost and to protect the environment [13]. Jangid and Darade [14] mixed black cotton soil with different proportions of fly ash ranging between (10-50) percent as a stabilizer to produce a compressed stabilized block. The produced block has a maximum increase in compressive strength at 10% fly ash ratio compared to conventional burnt clay brick. Meanwhile, the compressive strength reached the minimum at the fly ash ratio of 50%.
Nagaraj and Shreyasvi [15] produced CSEB from various proportions of cement, lime, and iron waste. Results showed that the wet compressive strength of the compressed stabilized earth brick was greater than 5 MPa after 6 months. This value is suitable for the compressed stabilized earth brick that is used to construct the residential buildings.

Hwang and Yehualaw investigated the performance of the compressed and stabilized earth blocks that used varying types and ratios of stabilizers agent (wood ash, lime, and cement). Wood ash and lime are the desired stabilizers to produce compressed stabilized blocks. They have better behaved if they were mixed with cement. 5% lime and 5% cement, 5% wood ash and 5% cement were the ideal mixtures to perform a desirable quality of compressed stabilized earth blocks [16].

Apparently, the most universally agreeable value to evaluate the quality of compressed stabilized earth units is compressive strength. However, they are strongly correlated with stabilizer content, soil types used, and the compaction pressure used to form the block. Usually calculating the compressive strength in the moist condition gives a lower strength value. The decrease in the saturated state can be related to the development of water pressure in the pores, which leads to the liquefaction of unstable clay minerals within the brick paste [17].

The strength of compressed and stabilized earth units can be increased by adding fiber as they improve the ductility in tensile through delaying the occurrence of tensile cracks as well as delaying its development and growth after its initial occurrence [18]. When used in compressed stabilized earth units, fibers create a network with a matrix that reduces plastic shrinkage cracking and improves ductility, tensile and shearing strengths. Prasad et al. [19] observed increasing in compressive strength of mud bricks due to the geometric shape of the fibers materials used and resistance to fiber sliding. On the basis of ecological metrics, natural fibers are preferable for CSEB reinforcement because of their being derived from renewable resources that are generally readily available at affordable costs [20]. Taallah and Guettala [21] studied the properties of compressed earth block in the presence of date palm fibers and quicklime fibers. They noticed that fiber face treating did not enhance adhere between fiber and matrix, so decreasing the strength of the block. Incorporated date palm fibers cause lower bulk density and thermal conductivity and thus increment the capillary absorption.

The compacting of compressed and stabilized earth units also affects compressive strength, since increasing the amount of applied pressure during compaction from 10 to 40 N/mm² will cause an increase in compressive strength of about 70% [22]. Mansour et al. [23] studied the effect of compaction pressure on bulk density, as well as the effect of bulk density on mechanical properties and thermal performance of the compressed and stabilized earth units. They found that compaction pressure affected the bulk density significantly. In addition, both thermal conductivity and thermal diffusivity decreased with bulk density.

On the other hand, there is a large contrast between compressed stabilized units and the usually burned bricks in terms of energy consumed through manufacturing and carbon emission. Compressed stabilized units emit 22 kg CO²/ton compared to concrete blocks (143 kg CO²/ton), standard burned bricks (200 kg CO²/ton) and cellular concrete blocks (280-375 kg CO²/ton) during production. On average, compressed and fixed earth units consume about 10% less energy than those used in the manufacture of burnt bricks and concrete blocks [24]. In addition, unfired clay masonry has been shown to provide passive environmental control in buildings by buffering both humidity and temperature fluctuations which resulted in reduced heating, cooling and ventilation demands [25].

The study’s aim is the produce building bricks from compressed soil and stabilized with cement and silica fume also to definite the mixes which yield the preferable properties result. Moreover, it is an attempt to replace the burnt bricks which consider as huge resource to gases and his roles in environmental deterioration with environmentally friendly building units.

2. Experimental Work
Hereafter the materials used, preparation of specimens, casting, compacting and curing, and testing program.
2.1. Materials

2.1.1. Soil
The soil was obtained from a pit at depth 1m under topsoil from Al-Zaafarania region in Baghdad. Firstly, removing the foreign objects like stone, plant’s roots then left the soil sample to dry by air. Afterward, crushing the soil sample with a wooden mallet and passed from a 2mm sieve prior to determine its characterization. The Atterberg Limits of the soil were determined according to ASTM D-4318 [26], Water content and specific gravity according to ASTM D4959-16 [27] and ASTM D854-14 [28] respectively. In addition to calculating other physical and chemical properties which showed in table 1. Sieve analysis was carried out to determine soil particle size distribution according to ASTM D6913M [29]. The result of the sieve analysis test was shown in table 2.

Table 1. physical and chemical properties of soil.

| Physical properties |  |
|---------------------|---|
| Specific gravity    | 2.67 |
| Appearance density  | 1730 |
| Water content (%)   | 16.4 |
| Liquid limit (%)    | 27.8 |
| Plastic limit (%)   | 14.35 |
| Plasticity Index    | 13.2 |

| Chemical properties |
|---------------------|
| SO₃ = 1.47          |
| PH = 8.81           |

The plasticity index of 13.2% indicated that the soil is cohesive and has the ability to endure proper compressing to improve the strength characteristics of the product’s bricks. Moreover, the soil is appropriate to stabilize with cement due to the value of the plasticity index that doesn’t exceed 15% as defined by [8].

Table 2. particle size distribution for soil.

| Sieve No. | Size mm | Wt. Soil retained (gm.) | Wt. % retained | Cum. % Wt. Retained | Wt. % passing |
|-----------|---------|-------------------------|----------------|---------------------|--------------|
| 4         | 4.75    | 2.1                     | 0.59           | 0.59                | 99.41        |
| 8         | 2.36    | 7.8                     | 2.2            | 2.79                | 97.21        |
| 16        | 1.18    | 4.6                     | 1.3            | 4.09                | 95.91        |
| 30        | 0.6     | 14.6                    | 4.1            | 8.19                | 91.81        |
| 50        | 0.3     | 7.5                     | 2.1            | 10.29               | 89.71        |
| 100       | 0.15    | 1.9                     | 0.53           | 14.82               | 85.18        |
| 200       | 0.076   | 50.2                    | 14.14          | 28.96               | 71.14        |

The particle size distribution test indicated that the soil sample is greater in fine grade (600-75) μm and classified as silty clayey soil.
2.1.2. Sand
Natural river sand was used from Al-Elkader region. Tests were performed to determine properties. Results indicate that the sulfate content and grading comply with the requirements of Iraqi Standard IQS 45-1984 [30], as shown in table 3.

### Table 3. Physical properties and sieve analyses of sand.

| Sieve size, (mm) | Cumulative Percentage passing (%) | Limits of Iraqi Standard IQS 45-1984 [30] |
|------------------|----------------------------------|----------------------------------------|
| 10               | 100                              | 100                                    |
| 4.75             | 96                               | 90-100                                 |
| 2.36             | 83                               | 75-100                                 |
| 1.18             | 69                               | 55-90                                  |
| 0.6              | 50                               | 35-59                                  |
| 0.3              | 22                               | 8-30                                   |
| 0.15             | 6                                | 0-10                                   |

### Physical Properties Test Results

- Specific gravity (no unit): 2.70
- Fineness modulus (no unit): 3.10
- Absorption (%): 0.5

2.1.3. Cement
Al-Mass Ordinary Portland cement has used (Type I) in this work. This cement is tested according to Iraqi standard specifications (I.Q.S 5:1984) [31]. Physical and chemical properties were conducted by the Central Organization for Standardization and Quality Control. Table (4) shows the physical and chemical properties of cement.

### Table 4. Physical properties and chemical composition of cement.

| Oxides      | %    | Iraqi specification No. 5/1984 [31] |
|-------------|------|-----------------------------------|
| CaO         | 60   | -                                 |
| SiO₂        | 21   | -                                 |
| Fe₂O₃       | 3.8  | -                                 |
| Al₂O₃       | 4.4  | -                                 |
| MgO         | 2.47 | <5                                |
| SO₃         | 2.12 | ≤2.8                              |
| K₂O         | 0.69 | -                                 |
| Na₂O        | 0.2  | -                                 |
| L.O.I %     | 2.7  | <4                                |
| Insoluble residue | 0.55 | <1.50                             |

| Properties | Cement | Iraqi specification No. 5/1984 [31] |
|------------|--------|-----------------------------------|
| Fineness (m²/kg) | 300 | ≥250 |
|-----------------|-----|------|
| Setting time (hr:min) | | |
| Initial | 65 min | ≥ 45 min |
| Final | 6 hrs. | ≤ 10 hrs. |
| Compressive Strength (N/mm²) | | |
| 3 days | 20.45 | > 15 |
| 7 days | 31.55 | > 23 |

### 2.1.4 Silica Fume

Used as pozzolana material with cement for stabilized compressed earth block in the study. The physical and chemical properties of silica fume are mentioned in table 5.

**Table 5.** Properties of silica fume.

| Chemical Composition | ASTM C1240 [32] |
|----------------------|------------------|
| Oxides               | Content %        |
| SiO₂                 | 95.48            |
| Fe₂O₃                | 0.16             |
| Al₂O₃                | 1.4              |
| CaO                  | 0.62             |
| MgO                  | 0.32             |
| SO₃                  | 0.55             |
| L.O.I                | 1.41             |
|                      | ≥ 85             |
|                      | ≤ 4              |
|                      | ≤ 6              |
| Specific surface area (m²/g) | 15.8 | ≥ 15 |
| Specific gravity     | 2.11             |

### 2.1.5 Water

Tap water was used.

### 2.2 Mixture’s Nature and Mix Proportions

The study plan included select different ratios for stabilizer content (cement and silica fume). There are 7 types of mixes which are (M1) 100% soil or unstabilized; (M2) bricks stabilized with sand by 20% soil replacement; (M3) bricks stabilized with cement 10% soil replacement; (M4) bricks stabilized with sand 20%, cement 8%, and silica fume 2% soil replacement; (M5) bricks stabilized with sand 20%, cement 7%, and silica fume 3% soil replacement; (M6) bricks stabilized with sand 20%, cement 6%, and silica fume 4% soil replacement; (M7) bricks stabilized with sand 20%, cement 5%, and silica fume 5% soil replacement. Table 6 reports the encoding of mixes and their details.
Table 6. encoding and details of mixes.

| Mix Code | Mix proportion (%) | Soil | Sand | Cement | Silica fume | Total Sample |
|----------|---------------------|------|------|--------|-------------|--------------|
| M1       | 100                 | 0    | 0    | 0      | 0           | 100          |
| M2       | 80                  | 20   | 0    | 0      | 0           | 100          |
| M3       | 70                  | 20   | 10   | 0      | 2           | 100          |
| M4       | 70                  | 20   | 8    | 2      | 3           | 100          |
| M5       | 70                  | 20   | 7    | 3      | 5           | 100          |
| M6       | 70                  | 20   | 6    | 4      | 100         |
| M7       | 70                  | 20   | 5    | 5      | 100         |

2.3 Samples preparation
Preparing and weighing the required quantity of raw materials for every trial to make batches of 9 bricks each. Dry components were mixed by mechanical mixer thoroughly for five minutes roughly before adding gradually the determined amount of water. The ingredients were then properly mixed for about five minutes. Thereafter, the mixtures cast into steel mould that has interior dimensions (80 x 120 x 240) mm, and compacted with steel rod unto the mold was fills up completely. Iron thick plate put upon the top surface of the mix with and pressing 20 N/mm² by a hydraulic loading machine. After completing the pressing process, the produced bricks were removed from molds and covered with nylon sheets to prevent moisture loss and left overnight at room temperature to allow setting. Thereafter, the curing process begins in a plastic shed and keeps moist by the adequate sprinkling of water daily for 28 days to complete the hydration reaction. Lastly, the compressive strength, water absorption, and density tests were undertaken at 28 days old of the product bricks.

3. Results and Discussion:
3.1 Compressive Strength
The compressive strength test results listed in table 7. The operation contains three samples for each group. Sample M7 of soil blended with sand and stabilized with an equal percentage of cement and silica fume indicated the greatest compressive strength (15.76 MPa) as shown in figure 2. It turned out that this is the optimal percentage of cement and silica fume content and records excellent strength for brick produced that match with class A of burnt bricks comply with Iraqi specification No. 25/1988. The other groups of the samples with a soil stabilized with different percentages of cement and silica fume (M6, M5, and M4) achieved compressive strength lower than that of sample M7 however records were good and match with class B of Iraqi specification. Otherwise, samples M3 with soil stabilized with cement only without silica fume observed compressive strength (10.85 MPa) which was lower than the sample M4 and match with class C of Iraqi specification. Silica fume is a very reactive material react efficiently with the calcium hydroxide produced by the hydration of cement to form calcium silicate hydrates which binding the particles with each other strongly and led to improving the compressive strength of produce bricks [34]. So, the compressive strength increased with increment in percentages of replacement cement with silica fume. The samples (M1) produced from the soil only have a lower compressive strength (3.62 MPa) while it doubled to (7.18 MPa) when soil blended with sand (M2) because the strength of compressed earth units produced from silty clayey soil with sand is higher than those units without sand [35].
### Table 7. Compressive strength test’s results.

| Mix Code | Average Compressive strength (MPa) |
|----------|-----------------------------------|
| M1       | 3.62                              |
| M2       | 7.18                              |
| M3       | 10.85                             |
| M4       | 12.49                             |
| M5       | 13.27                             |
| M6       | 14.52                             |
| M7       | 15.76                             |

![Figure 2. Average compressive strength results for all mixes.](image)

### 3.2 Water Absorption

Table 8 and figure 3 point to the water absorption test results to the brick samples produced. The test contains 3 samples from each group after finished curing for 28-days. The samples were dried in the oven and weighed then submerged in water for 24 hours and again weighed. The difference between wet weight and dry weight relative to dry weight is equal to the amount of water absorption of samples. The rate of absorption water improved significantly according to the type of stabilizer and its proportion. The unstabilized soil brick sample (M1) doesn’t record any result because the sample disintegrated after 24 hours into the water, while sample (M2) of soil blended with sand recorded 21.28% due to presence of sand. Among other building materials, an unstabilized block absorb more moisture [24]. The result of water absorption of sample M2 was encouraging to comprehend the advantage of adding sand to make compressed stabilized bricks. Cement as stabilized when used in sample M3 played a good role in decreasing water absorption to be 14.33%. The result proved that the cement agglomerates the soil particles and decrease pore’s size as water will run into the brick. Otherwise, insert silica fume with cement as stabilizer decreased the absorption of water to a large extent because of silica fume can produce very large reductions in water permeability due to high pozzolana reaction rate that result in minimizing the size of capillary pores and creates a very dense material that prevents water from passing through it to some extent. Water absorption continues to decrease with increasing silica fume percentage, where the
rate of samples (M4- M7) ranges between (11.63-6.09) %. The lowest ratio of 8.09% was gained by the soil stabilized with equal percentages of cement and silica fume (M7).

Table 8. Water absorption test’s result.

| Mix Code | Average of Three Samples |
|----------|--------------------------|
|          | Dry Mass (Kg) | Wet Mass (Kg) | Water Absorption (%) |
| M1       | -             | -             | -                    |
| M2       | 16.12         | 19.55         | 21.28                |
| M3       | 15.35         | 17.55         | 14.33                |
| M4       | 14.53         | 16.22         | 11.63                |
| M5       | 13.87         | 15.27         | 10.09                |
| M6       | 14.44         | 15.64         | 8.31                 |
| M7       | 14.12         | 14.98         | 6.09                 |

Figure 3. Average water absorption rate for all mixes.

3.3 Dry Density
The dry densities results are briefed in table 9. The dry density of compressed unstabilized soil samples (M1) values were 1530.4 Kg/m³, whilst all other types with different proportion of stabilizers recorded values of dry density more than 1530.4 Kg/m³. The combination of an equal percentage of stabilizers (cement and silica fume) achieved the highest density of 1840.3 Kg/m³; while the density of samples (M4, M5, and M6) decreased as the silica fume percentage decreased and achieved dry density ranging between 1813.5-1833.7 Kg/m³ as shown in figure 4. As mentioned before, this can be attributed to the capacity of hydration products which formed heavily in the presence of the stabilizer materials that create a denser structure. This shows the positive role played by silica fume as a stabilizer and its effect on the properties of the bricks produced. Therefore, we notice that the dry density of the samples that stabilized with cement only (M3) was lower than all samples stabilized with silica fume and cement. Apparently, the dry density of bricks and compressive strength has a direct relation.
Table 9. Dry density test’s result.

| Mix Code | Average Dry Density (Kg/m³) |
|----------|-----------------------------|
| M1       | 1530.4                      |
| M2       | 1583.9                      |
| M3       | 1780.4                      |
| M4       | 1813.5                      |
| M5       | 1821.9                      |
| M6       | 1833.7                      |
| M7       | 1840.3                      |

Figure 4. Average dry densities for all mixes.

4. Conclusion

According to the test results, the subsequent conclusions were drawn:
1- Compressed and stabilized soil bricks are considered environmentally building materials because they are a non-burning product and therefore it is not necessary to have coal or electricity for combustion and reduce pollution of atmospheric.
2- Blended sand with soil used improve the properties that make soil more suitable for producing compressed and stabilized units with cement and silica fume.
3- Using cement to stabilized the brick produced enhances the compressive strength, water absorption, and dry density.
4- Silica fume as a stabilizer with cement significantly increasing the strength and density of the producing units as it is a pozzolana material.
5- Silica fume with cement contributes to reducing the water absorption to the brick produced as it reacts efficiently with the calcium hydroxide produced by the hydration of cement to form calcium silicate hydrates which binding the soil particles and minimized the pores.
6- Possibility to use compressed soil bricks stabilized with silica fume and cement as alternative to burnt bricks, since the bricks produced to comply with class A and B of Iraqi specification.
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