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Northern Kuwait Soil Evaluation in Producing Environmentally Friendly Blocks

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Abstract **-** This paper presents the initial results of the evaluation of soil samples collected from the northern regions of Kuwait, in addition to the preliminary results of Compressed Earth Blocks (CEB) compressive strength tests for different mix designs. The performed tests and the produced blocks are part of a series of tests that evaluate the applicability of producing environmentally friendly construction blocks. The overall purpose of this study is to introduce a construction material that can be of environmental benefits to the Gulf Cooperation Council (GCC) region to reduce the construction industry impact on the CO_2 emission in the region. Soil samples were collected from Boubyan Island and Sabriya area, located in northern Kuwait. Basic engineering properties of the samples were obtained, including the soil gradation, the Atterberg limits, and the Optimum Moisture Content (OMC). Subsequently, 24 mix designs of CEB were tested to evaluate their compressive strength. The results showed that increasing the percentages of the clayey/silty soil in the block mixtures reduces the compressive strength of blocks with high cement percentages. Whereas compressive strength of blocks containing low cement percentages were increased with the increase of clayey/silty soil percentages to a certain extent. The study recommends that the soil/sand ratio is limited to 1.0.

Keywords**:** Compressed Earth Blocks, Compressive Strength, Soil Evaluation, Sustainable Construction Materials

1. Introduction

Several research studies attempted to find solution(s) for the crawling of concrete buildings into the desert areas, which is one of the highest demanding environmental problems in the Gulf region. In addition, accelerated construction & building industry in the GCC is one of the high contributors to the elevated per capita carbon dioxide emission of these countries [1]. Earth structures have been used for centuries due to the abundance of its components. In fact, about 30% of the current population of the World live in homes made from earth structures [2]. CEB is one of the many types of blocks made from natural stabilizers, normally clayey or loamy soil mixed with coarser granular soils then moulded and subjected to high compression (either manually or mechanically) [3, 4]. CEB are advantageous over other construction techniques for their minimal production efforts, their lower cost, and their less need of skilled construction labour. They have been proven as a feasible construction material that can replace traditional concreting in one to two-story buildings in both humid and dry environments, they also provide a more environmentally friendly alternative than the traditional cementitious bricks at a high quality [5]. Research work on CEB can be traced back to the 1950s (e.g., [6, 7]). Various studies on CEB performance and production manuals (e.g., [3, 8, 9 and 10]) recommended using certain types and grain size distributions of soil in the manufacturing of CEB. According to [11], several locations in Kuwait contain clayey and silty soil deposits that can be used in CEB production. The highest clayey and silty compositions in Kuwait were found in Boubyan Island and the nearby sites located in Sabriya area [12]. This research study aims at evaluating soil samples from these locations and evaluate the performance of initial mix designs for CEB made with the extracted soil from these locations.

2. Soil Collection

The first step of this study was to collect samples from the northern areas of Kuwait (Boubyan Island and Sabriya area), shown in Figure 1. Samples of soil were collected from different locations to help identify the differences in soil properties with varying locations. Visual investigations of the soil followed by a physical inspection were used to identify the best locations; soils with a crumbling texture were avoided whereas clayey mouldable soils were collected (see Figure 2).

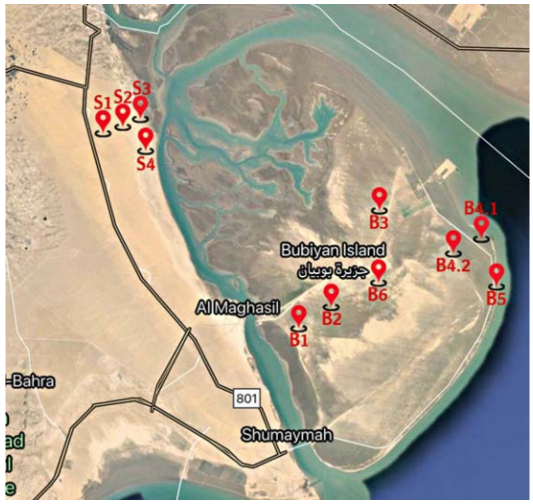

Fig. 1: Boubyan Island map with locations of different samples

Several pits were made at each location to ensure that the collected soil samples represent the existing soil in this location. Each pit had an average depth of 800 mm to ensure no surface salinization contaminates the collected soil thus preserving the homogeneity of the collected soil samples. Samples were then labelled B1 to B6 for the soil collected from Boubyan Island and S1 to S4 for the soil collected from Sabriya Area.


(a) (b) (c)

Fig. 2: (a) Soil sample pit from Boubyan Island (b) Visual inspection of the soil, and (c) physical inspection of the soil (moldability)

2. Soil Properties

Three main tests were performed to identify/ classify the soil: 1- soil gradation (sieve analysis), 2- optimum moisture content (OMC), and 3- Atterberg Limits.

2.1. Soil Gradation (Sieve Analysis)

Since the soil grain size and type are of utmost importance to the quality and performance of the produced CEB, sieve analyses were performed on all the collected soil samples. It was done according to the ASTM C117 standards [13]. The gradation charts for all collected samples from Boubyan Island and Sabriya area are shown in Figure 3, with the minimum and maximum limits recommended by [8] for use in CEBs shown as black lines.

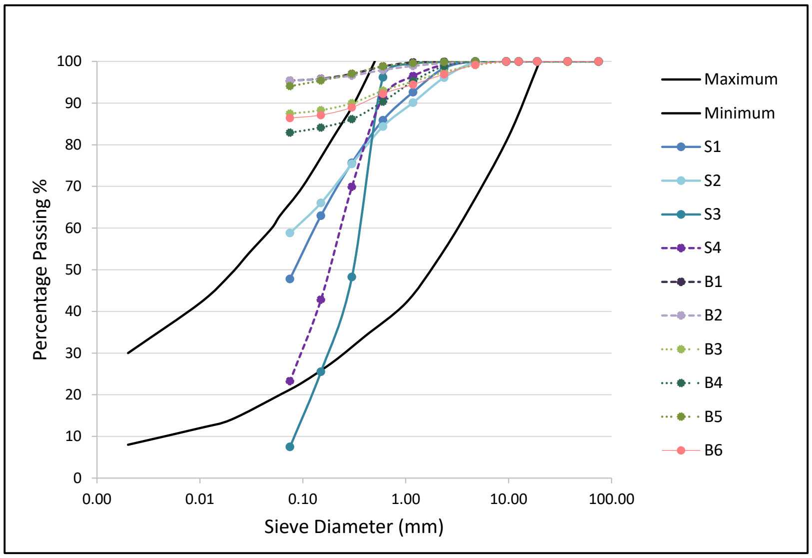

Fig. 3: Soil gradation for the collected soil samples vs the minimum and maximum limits set by [8]

The collected soil samples from Boubyan Island had very high percentages of fine particles (between 82% and 96%). They fell outside the range set by the CEBs production standards, which means that they shall be mixed with larger grain-sized soil before production. Whereas the Sabriya area soil samples contained larger grain sizes (mixtures of sandy and silty soils), but with no clay textures (low plasticity).

2.2. Atterberg Limits

Atterberg limits were obtained using ASTM D4318 standard [14] to help in classifying the soil fine particles. Liquid Limits (LL) and Plasticity Indices (PI) were obtained for the 7 different samples collected from Boubyan Island. The remaining samples (collected from Sabriya area) did not have enough plasticity to perform the test because they contained larger grain sizes (sandy soil) as seen from the sieve analysis results. Table 1 shows the resultant LL and PI of all tested samples.

Table 1 Atterberg Limits for Boubyan Island soil samples

Sample	LL	PI	Indication on Chart
B1	27.06	4.01	
B2	29.77	4.26	
B3	37.33	8.86	
B4-1	35.23	13.82	
B4-2	37.28	6.87	
B5	43.12	2.42	
B6	32.3	7.02	

When plotting these results on the Unified Soil Classification chart (Figure 4), the samples fell within two main soil classifications: (1) ML (Inorganic Clayey Silts with slight plasticity) and (2) CL (Inorganic Clays with low to medium plasticity). It should be noted that all samples had LL values lower than 50%, which indicates a clayey or silty soil with low plasticity.

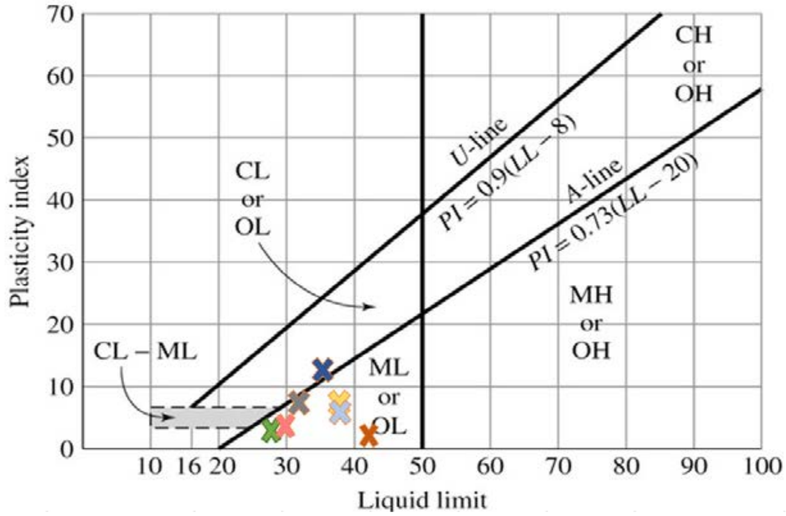

Fig.4 Atterberg limits test results on the Unified Soil Classification chart

2.3. Optimum Moisture Content

Since CEBs are made of a combination of different soil types (clayey/silty and sandy soils) using compression mechanisms, it is important to determine the OMC that can result in the highest dry density, which in turn enhances the performance of the produced blocks. Different ratios between sand and the collected clay/silt soil were made and the OMC charts were plotted as shown in Figure 5. A summary of the obtained OMC for the studied ratios is presented in Table 2. Since the OMC did not drastically change with the change of sand/soil ratios, it was decided to use an average OMC of 10% for all the produced blocks in the study. These procedures were done in accordance with ASTM D1557 standard [15] using the Modified Effort Test (known as The Modified Proctor Compaction Test).

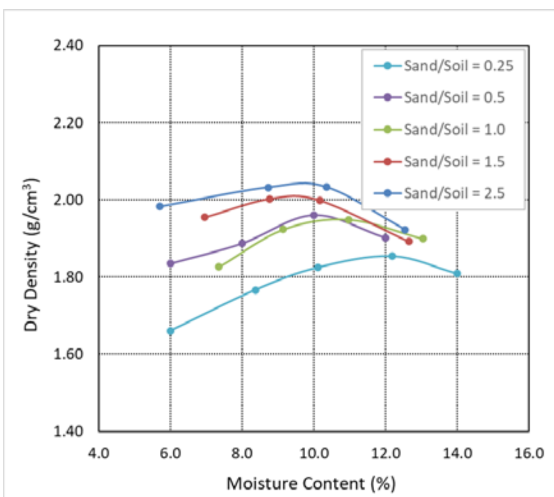

Fig. 5: Resulting dry densities vs. moisture contents for different sand/clay ratios

Table 2: OMC for different sand/clay ratios

Sand/Clay Ratio	OMC
0.25	12
0.5	10
1	10.5
1.5	9.5
2.5	10

3. CEB Mix Designs

A total of twenty-four different mix designs were tested with various ratios of cement, sand, and soil (clay), alongside the moisture content of 10% to ensure compaction is done properly. A testing protocol was used as a guide for the tested mix designs. To design the protocol, cement ratios were used to separate different sets of mix design groups, starting from 15% cement in Set-1 down to 2.5% cement in Set-4. This was done to limit the effect of cement ratios on the blocks, and to focus on the soil/sand contributions to the CEB compressive strength, while also observing the optimal cement percentage that can be used in a CEB mix. As for the sand and soil, all mixes started with only sand (no soil), which is the current industrial practice for Concrete Masonry Units, and then percentages of the sand were substituted gradually with soil to study the effect of added soil on the block strength. Table 3 shows the tested mix designs with percentages of all ingredients.

Table 3: Mix Designs of the study

Set	Mix Name	Cement Percentage	Sand Percentage	Soil Percentage	Set	Mix Name	Cement Percentage	Sand Percentage	Soil Percentage
1	1.0	15	85	0	3	3.0	5	95	0
	1.1	15	60	25		3.1	5	60	35
	1.2	15	50	35		3.2	5	50	45
	1.3	15	40	45		3.3	5	40	55
	1.4	15	30	55		3.4	5	30	65
	1.5	15	20	65		3.5	5	20	75
2	2.0	10	90	0	4	4.0	2.5	97.5	0
	2.1	10	60	30		4.1	2.5	60	37.5
	2.2	10	50	40		4.2	2.5	50	47.5
	2.3	10	40	50		4.3	2.5	40	57.5
	2.4	10	30	60		4.4	2.5	30	67.5
	2.5	10	20	70		4.5	2.5	20	77.5

4. Testing and Results

Block dry compressive strength tests were done in accordance with ASTM C140 standards [16] at 7 and 28 days. The compressive strength results, as illustrated in Figure 6, indicate that increasing the clayey soil percentages in Set-1 mix design (highest cement percentage) decreases the block compressive strength. Which means that replacement of the larger grain sizes of the sand with clayey soil had a negative impact on the compressive strength performance of the block. For Set-2, similar conclusion can be driven, but with a lower reduction in the block strength than Set-1. For Set-3 and Set-4 (5% and 2.5% cement contents, respectively), the compressive strength of the blocks increased with the addition of soil to the mix design up to a soil/sand ratio of 0.75 (for Set-3) and 1.0 (for Set-4). The reason for such behaviour is the lack of enough stabilization provided by the cement, which was compensated by the clay content at the early soil/sand ratios.

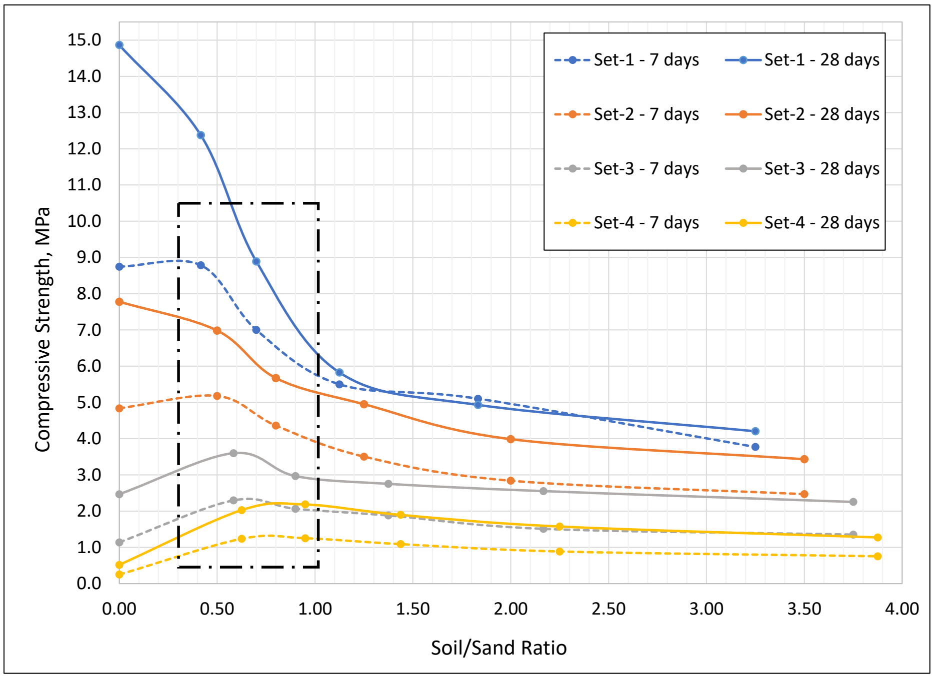

Fig. 6: Compressive strength of the CEBs vs. the soil/sand ratio

Further increase of the clay content for these two sets (Set-3 and Set-4) resulted in a decrease in the compressive strength because of the large granular soil replacement in the blocks. It can also be seen that the rate of change in the blocks compressive strength beyond a soil/sand ratio of 1.0 is relatively small with a continued decrease in the block strength. All sets with different cement percentages exhibited a reduction in the compressive strength for Soil/Sand ratios larger than 1.0, which means that regardless of the used stabilizers, the soil (clay/silt) amount used in the CEB production shall not be larger than the amount of sand used in the mix design.

4. Conclusion

This research study is part of ongoing research effort to evaluate the applicability of CEBs as an alternative construction technique in the GCC countries, especially in Kuwait. The study started by soil evaluation of the northern areas in Kuwait, where clayey and silty soil deposits exist. The initial soil evaluation concluded that the soil in these areas are inorganic clayey silts with slight plasticity (ML) and inorganic clays with low to medium plasticity (CL). Twenty-four mix designs of CEBs were produced from soil collected from the northern areas of Kuwait and tested for compressive strength. The mix designs had various percentages of cement, sand, and soil (clay/silt) Their compressive strength values were obtained at 7 and 28 days. It was concluded that, for blocks with high cement ratios, increasing soil percentages in the mix design reduces the compressive strength of the blocks, regardless of the soil/sand ratio. Whereas adding limited soil amounts to sets with low cement percentages improves the blocks compressive strength. For all mix designs, irrespective of the cement ratio, it is recommended to limit the soil/sand ratio to 1.0.

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