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PROPERTIES OF SOIL-CEMENT BLOCKS MANUFACTURED USING PRODUCED WATER FROM OIL FIELDS: A PRELIMNARY INVESTIGATION

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ABSTRACT: One of the prime aims of the sustainable development strategies in many countries is to provide safe and secure environment for their inhabitants. This goal can be achieved through the use of environmental friendly building materials, commonly referred to as green building materials and the effective use of waste materials in useful applications such as construction industry. In Oman, saving the environment by finding alternative useful methods for re-using different kind of wastes and seeking ways to reduce the emission of harmful gases, and looking for affordable low-income housing for people are of great concern to the authorities in order to preserve and sustain the environment for the future generations. In order to fulfill such objective, research into the use sustainable materials in the construction industry is encouraged. Therefore, in the same context, this paper discusses the preliminary results from an ongoing research study on the use of produced water from the Petroleum Development Oman (PDO) Nimr and Marmoul oil-fields in the development of a new soil-cement block which possesses good strength, good thermal insulation and consume lower quantity of cement than the conventional one. Soil and water samples were brought from Marmoul and Nimr sites. The initial results indicated that both soil and water are suitable for production of compressed blocks with good mechanical properties.

Keywords: Soil Compressed blocks, Produced Water, Oil-fields, Strength

1. INTRODUCTION

One of the roles of the sustainable development strategies in the developing countries is to provide decent welfare to the community through providing the basic needs to its people such as clean and potable water, housing, safe environment, etc. at affordable and cheap means. Therefore, in many developing countries, it is necessary to seek ways to reduce construction costs, especially for low-income housing, as well as adopting easy and effective solutions for their repair and maintenance [1]. This objective can be partially achieved through the use of locally available materials in the construction of low-income housing. Soil is found in abundant quantities all over the world. Its use in the construction industry is significant in applications such as cement mortars, concrete, finishing, cement blocks, and soil compressed blocks and bricks. Compressed earth block (CEB) system is one of the traditional construction systems that exists in many developing countries which have proved to be suitable for a wide range of buildings and which have a great potential in the construction of traditional low-cost dwellings. Adam and Agib [1] reported that soil construction methods are used in 80% of urban buildings and exceeds 90% in rural areas in Sudan. Often a stabilizer material such as cement or lime is added in small quantities in order to improve the mechanical properties and durability of the blocks. These blocks are usually used in non-load bearing construction.

Freshwater is a precious and scarce commodity in all arid regions such as Oman and other Gulf countries. This commodity becomes increasingly more valuable in these countries as they witness a rapid development in their urban infrastructure including buildings, hospitals, homes, and roads. Water is needed in road construction where it is used as mixing water for compaction and for dust control. It is also needed as a component in concrete mixtures, primarily for the hydration process of cementitious materials and for curing. Contractors in arid regions, and especially in remote areas of the desert, are sometimes faced with the problem of finding water of acceptable quality for their construction work. However, plenty of non-freshwater (oily and brackish water) is produced in the oil fields during oil exploration. Water produced with oil forms the largest amount of waste in the entire oil production process. An oil field typically produces more than five times the volume of water as oil during its economic life. In Oman, the PDO production of water from oil-fields was nearly 850,000m³/d in 2015.

Approximately 9 barrel of water is produced for each barrel of oil. Therefore, PDO is very keen to seek for alternative viable uses of oil produced water (oily water) that can help consuming such large quantity of water. The main objective of this research study is to investigate the potential use of non-fresh water (brackish and production water) from Nimr and Marmoul PDO oil- fields in the development of a new soil-cement block which possesses good strength, good thermal insulation and consume lower quantity of cement than the conventional one.

2. MATERIALS AND TESTING METHODS

2.1 Soil

Two types of soil were provided from PDO oil fields: soil from Marmoul oil-field and that provided from Nimr oil-field. These soils are not contaminated soil. Field and laboratory tests were performed on the two soils to assess their suitability for block manufacturing. Chemical analyses were carried out on the soil samples from Nimr and Marmoul sites to determine heavy metals, anions and organics, whereas tests to determine the physical properties of the soil which include specific gravity, Atterberg limits, shrinkage, and grading.

2.2 Produced Water

About 1000L of produced water was brought from each site. For the chemical analysis test of the produced water measurements included certain impurities that could affect soil-cement blocks such as: total alkalinity, sulfate content, chloride content, total dissolved solids and water hardness. Other parameters such as pH and conductivity were also measured. The water quality was compared with the international specifications for producing concrete i.e. ASTM C94 [2] and AASHTO M157 [3] as well as the U.S. Environmental Protection Agency (U.S. EPA).

2.3 Soil Stabilizer

Ordinary Portland cement (OPC) was used as a stabilizer in the production of Compressed Earth Blocks (CEB).

3. RESULTS AND DISCUSSION

3.1 Analysis of Soil Samples

3.1.1 Chemical analysis of soil

The results obtained from the chemical analysis test indicated that the chloride and fluoride contents in both sites soil samples are similar. The sulphate content in soils samples from Nimr (1000 mg/kg) is relatively higher than soil samples from Marmoul (800 mg/kg). In general, the content of heavy metals in Marmoul soil samples is relatively higher than the soil samples from Nimr. However, the leachability test has to be evaluated for any application of such soils.

3.1.2 Physical properties of soil

Specific gravity for the two soils was carried out in accordance with ASTM D854 [4]. Two samples from each soil were selected and tested to determine their specific gravity. The results show that the two soils have almost the same specific gravity of 2.69 in average.

The test results show that Marmoul soil has 29%, 18%, and 11%, liquid limit (LL), plastic limit (PL) and plasticity index (PI), respectively, whereas these values were zero for Nimr soil. These tests were conducted in accordance with ASTM D4318-98 [5]. The results indicated clearly that Nimr soil contains more sand/silt and has no plasticity. For Marmoul soil, liquid limit LL= 29% and plasticity index PI= 11%. Both values fall within the limits specified by ARS 680 [6] for production of compressed blocks. However, since Nimr soil has no plasticity, its suitability has to be assessed by other tests.

Sieve analysis test was carried out in accordance with ASTM D422-63 [7] to determine the distribution (grading) of the soil particles for different sizes. To produce a soil-cement block with good properties, the soil should contain 15% gravel, 50% sand, 15% silt, and 20% clay at the most. Since soil contains fine particles i.e. silt and clay, performing sieve analysis test alone is insufficient to classify the soil. Therefore, to classify Marmoul and Nimr soils, three analyses tests were conducted, sieve analysis test, wet sieve analysis test, and hydrometer test for soil particles passing 75µm. Results are given in Table 1. The particle distribution curves for the two soils were plotted together with the limits by ARS 680 [6] in Fig. 1. It is clear from the figure that, the two soils have almost the same distribution; both are within limits specified by the code ARS 680 [6] for compressed earth blocks but Nimr soil suits well within those limits.

Also, the results showed that, while the quantity of clay in the two soils are almost the same (2.25% for Marmoul and 2.02% for Nimr), Nimr soil contains more silt than Marmoul soil (18% compared to 11%). The quantity of clay in the soil controls the selection and the amount of the stabilizer. For soils with high clay content, only lime can be used to stabilize the soil. With the low clay content as in Marmoul and Nimr soils, cement can be used as a stabilizer prior to compressing the soil. However, the quantity of the cement stabilizer can be determined by testing a number of mixes with various stabilizer proportions. Soils with higher clay contents compress more than those with lower clay content. In the present case, it is expected that Marmoul soil will require more volume of soil to make the same block than of Nimr soil, due to its higher compressibility.

Table 1 Particle size distribution of the soils from oil fields

Sieve Size (mm)	%Passing Marmoul	%Passing Nimr
9.5	99	99
5	91	92
2.36	76	84
1.18	58	73
0.6	43	61
0.3	33	50
0.15	23	40
0.075	14	20
Clay Content	2.25	2.02

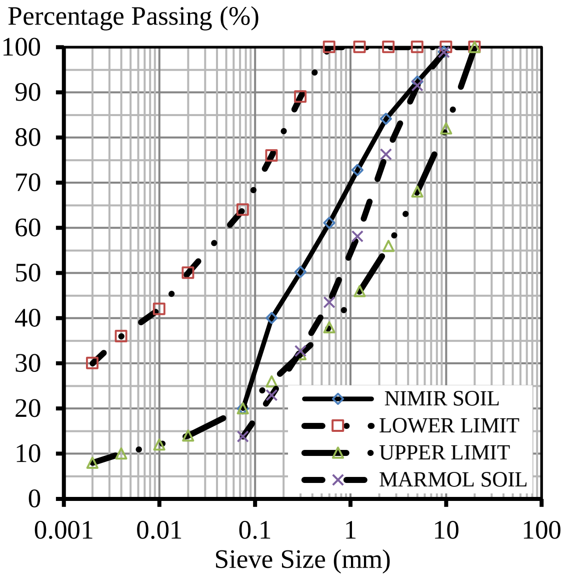


Fig. 1 Particle size distribution for Nimr and Marmoul soils

The shrinkage test measures the shrinkage of the soil which contains no stabilizer, and the result can be used to give a rough guide for estimating the required amount of cement as a stabilizer. After seven days of casting, Nimr sample did not show any shrinkage in the length. No cracks could be detected on the surface of the specimen. The Marmoul specimen showed one hairy crack on its top surface near the middle of its length. At one end it separated from the mould. The contraction was about 0.5mm.

3.2 Analysis Results of Water

Results from the chemical analysis tests are shown in Table 2. It can be seen from Table 2 that the salinity (electrical conductivity) of the produced water samples from Nimr is higher than the ones from Marmoul. This is evident from the higher Total Dissolved Solids (TDS) values (8300 mg/L in Nimr water sample compared to 4780 mg/L in Marmoul water sample). Moreover, the chloride content in Nimr water samples (4378 mg/L as Cl-) is higher compared to Marmoul water samples (2136 mg/L as Cl-). The sulphate (as SO_4) and hardness (as $CaCO_3$) contents in Nimr water samples (333 mg/L and 350 mg/L) are higher compared to Marmoul water samples (120 mg/L and 140 mg/L). However, total alkalinity (as Na_2O) in Nimr water samples (190 mg/L) is lower compared to Marmoul water samples (472 mg/L). The content of heavy metals is relatively low in the water samples from both sites (most are below detection limit except Boron which was in the range of 4 mg/L). Moreover, oil and grease content was found below detection limits in the water samples from both sites (i.e. less than 5 mg/L).

Water quality specifications for producing concrete mixes according ASTM C94 and AASHTO M157 [2], [3], [8] are shown in Table 2. It can be seen that both water samples from Nimr and Marmoul meet the limits of total solids (<50000 mg/L), sulphate (<3000 mg/L) and alkalinity (<600 mg/L). However, the chloride content is higher than the specified maximum limits (>500 mg/L). Therefore, further analysis on the production of bricks has to be conducted.

Table 2 Water quality specifications for producing concrete (adopted from Chini et al. [8])

Chemical Limit mg/L	Specification ASTM C94	AASHTO M157	NR	ML
Sulphate as SO_4	3000	3000	333	120
Total Chloride as Cl^-	500	1000	4378	2136
Total solids	50000	50000	8300	4780
Alkalis as Na_2O eqv.	600	600	190	472

NR: Nimr water, ML: Marmoul water

3.3 Production of Soil-Cement Block

Stulz et al. [9] defined compressed earth blocks (CEBs) as “masonry elements, which are small in size with regular and verified characteristics obtained by the static or dynamic compression of earth in a humid state followed by immediate demoulding”. Compressed earth block system is one of the traditional construction materials that exists in many developing countries which has proved to be suitable for a wide range of buildings and which have a great potential in the construction of traditional low-cost dwellings.

These blocks are composed of earth material (soil) whose cohesion is due principally to the clay fraction present in both humid and dry states [10]. The properties and cohesion of the CEBs can be enhanced by the addition of a stabilizer. The quality of these blocks depends on the type of the raw materials used i.e. the soil and the stabilizer, and on the steps and expertise in executing various stages of manufacturing i.e. the preparation of materials, addition and mixing of stabilizers and compaction or compression up to curing stage [10]. In order to produce soil-cement blocks which possess good properties, the most optimum constituent materials should be selected. The best soil suitable for the production of soil compressed blocks should be constituted of 15% gravel, 50% sand, 15% silt, and 20% clay. These properties should be determined before using the block. Also, the quality of the water used in producing the blocks should be analyzed especially if non-freshwater is to be used or the water to be used is of unknown source. Generally, typical wet compressive strengths of CEBs are within 4 MPa [1].

Three soil stabilization methods are usually used in the production of CEBs. Mechanical stabilization which involves compacting the soil in order to improve its resistance to shearing, compressibility, permeability and porosity. Physical stabilization which concerns with changing soil texture and properties as well as the use of different curing methods such as air or moisture curing, and heat treatment. Chemical stabilization is achieved by enhancing the physicochemical properties of the soil by the addition of chemicals. The most two widely used stabilizers in the production of CEBs are cement and lime. In this research cement will be used as the main stabilizer although the use of other materials such as lime or cement kiln dust (CKD) can be investigated.

Adam and Agib [1], and Oyelami and Rooy [10] reported many advantages of compressed earth bricks which are in line with the sustainable development objectives and strategies. In terms of materials efficiency, CEBs use 30% less water compared to what is used in other conventional building material production. They are produced mainly from soil, sustainable resource, which are recyclable, produce very little harmful air emissions, have zero or low toxicity, are durable and readily available [10]. CEBs are energy efficient material; the production of CEBs requires only 1% compared to a similar volume of concrete. About 36 MJ (10 kW h) of energy is required to produce 1m^3 of CEB in comparison with about 3000 MJ (833 kW h) that is required to produce the same volume of concrete. Since the density of CEBs is less than that of concrete, they possess less thermal conductivity than other conventional materials in building construction. Also, compressed earth blocks have much better fire resistance and sound proof than other parent materials. CEB is considered as environmentally friendly material since it reduces the consumption of excessive volumes of cement through the promotion and use of environmentally friendly earth materials that utilizes minimal quantities of cement and consequently decreases significantly CO_2 emission into the atmosphere. Oylemi and Rooy [10] reported that manufacturing of a ton of cement generates around 0.55 tons of CO_2 and the burning of carbon-fuel produces another 0.4 tons of CO_2. Some studies [10] showed that CEB generates about 22kg CO_2/ton whereas concrete blocks produce, nearly 143kg CO_2/ton, burnt clay bricks, about 200kg CO_2/ton and perforated concrete blocks 280 to 375 kg CO_2/ ton.

In this research, two types of CEB manufacturing machines will be used: a manual and a hydraulic press. These machines are manufactured by the Habitec Center at the Asian Institute of Technology, Thailand. Fig. 2 shows the manual CEB press whereas Fig. 3 shows a block sample produced using the manual press.

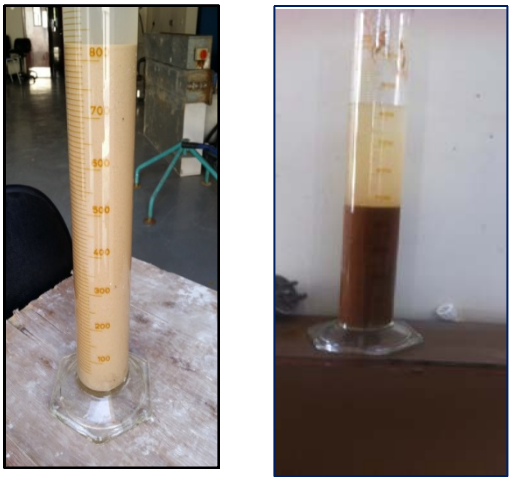
The manual press produces about 300 bricks per day while the hydraulic brick press can produce 3,000 bricks per day. Water requirement for the production is 2,250 liters per day. In tropical countries, the top layers of the earth (50cm) are not recommended to be used as the top soil contains plants and grasses, which are not good for brick making. The deeper soil that are mostly sandy, are found to be extremely good for the manufacturing of these bricks. Before mixing, the soil lumps must be broken up so that the lumps do not remain. Sand available in Oman could be normally used without any further processing (maybe with slight sieving). Hence, in order to produce good quality bricks, the content of these fine particles in the soil should be in such a proportion that the soil and sand content has optimum water content and clay particles. The bricks are produced by stabilizing with cement, and are air cured for 24 hours followed by water curing for 3 weeks. After 3 weeks, the bricks are ready to use for the construction works.

Fig. 2 The manual soil-cement block making press.

Fig. 3 Typical soil-cement block.

The brick making process is entirely a green process. It doesn't need furnace to process the bricks unlike in the conventional process. The bricks need water as an ingredient as well as for curing. The cement component of the bricks which are predominantly composed of clay and sand is less than 15% to attain strengths comparable or better than conventional bricks. The manufacture of good quality, durable compressed stabilized soil-cement bricks requires the use of soil containing fine gravel and sand for the body of the brick, together with silt or clay to bind the sand particles together. An appropriate type of stabilizer is added to decrease the linear expansion that takes place when water is added to the soil sample. The block is self-interlocking which requires minimum amount of mortar for block alignment and fixing leading to saving in cement used and an improvement in the thermal insulation of the wall by reducing the thermal bridges that are created at the mortar's line.

To study the possibility of using local soil in the production of cement-soil block, two locally available soils in large quantities were used. These soils are mountain soil and dune sand. Before using these soils in the manufacturing of the blocks, their suitability was assessed using the particle determination test which determines the soil particles content. Fig. 4 shows the particle determination test of the mountain soil and dune sand. It can be seen from Fig. 4 that dune sand sample contains one type of soil whereas mountain soil contains 50% soil and 50% clay. Therefore, the two soils cannot be used separately to make good compressed earth block, but they can be mixed together or with other soils to produce blocks that satisfy the requirements.



(a) Mountain soil (b) Dune sand

Fig. 4 Particle determination test

Four soil mixture proportions were prepared using mountain soil and dune sand, in addition to mixes using soil and water from Marmoul and Nimr oil fields as shown in Table 3. Cement was used as stabilizer and kept constant in all mixtures. Three water proportions were used ranging between 0.5 and 1.5. The manual press machine was used in the production of the blocks. Soil, dune sand and cement were mixed together. Then water was added to the mixture providing the necessary moist. The press mold was filled with the mixture and pressed using the pressing arm. After removing the blocks from the mold, they were then moved to the curing area and left for 24 hours in the open air under the shade. After 24 hours, the blocks were moved and stacked under the sun, covered with plastic covers and left to cure until the day of testing. The compressive strength test was carried out on the blocks after 28 days of curing as shown in Fig. 5.

The results presented in Fig. 5 show that the compressive strength of the blocks ranged between 0.87 MPa for Mix-02, 3 MPa for Mix-04, 5.25 MPa for MAR-01 and 5.54 MPa for NIM-01. The maximum strength using normal water and blended soil was achieved for Mix-04 with 4 proportions of mountain soil and 4 proportions of dune sand. In contrast, blocks from soil and water from the two oil fields gave 5.25 MPa for MAR-01 from Marmoul oil field and 5.54 MPa. Generally these mixtures can be modified in order to obtain better results in the future.

Table 3 Volumetric mix proportions for the soil cement block

Mix no.	Cement	Soil	Dune Sand	Water
Mix-01	1	8	0	1.5
Mix-02	1	2	6	0.5
Mix-03	1	3	5	0.75
Mix-04	1	4	4	0.75
NIM-01	1	8	0	1.5
MAR-01	1	8	0	1.5

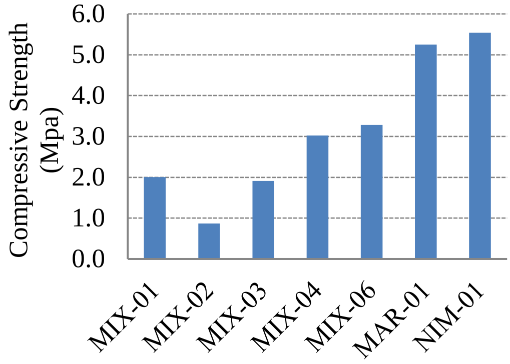


Fig. 5 Average compressive strength of blocks after 28 days of curing.

The compressive strength results were obtained using field compression testing machine which was supplied by the manufacturer of the manual and hydraulic press machines as shown in Fig. 6.

Fig. 6 Field compression testing machine.

The field compression machine applies compressive load on the block using a hydraulic jack connected to a hydraulic manually operated pump. The pump is provided with a dial gauge that measures the pressure in the piston. To get the actual load applied to the block by the piston, an electric load cell was placed between the piston and the bottom loading plate of the machine. The load was applied gradually while pressure readings of the pump gauge and the load cell were recorded. The correlation curve between the field testing machine reading and the load cell reading is shown in Fig. 7. It may be seen from this figure that there is an excellent correlation between the two parameters with R^2 value of 0.9987. The compressive strength values were obtained from Fig. 7 by dividing the failure load by the gross area of the block.

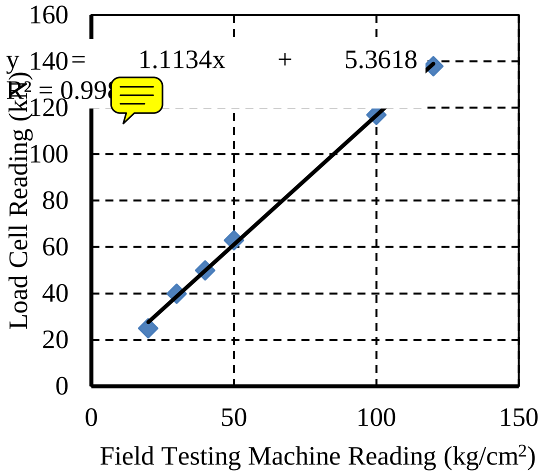


Fig. 7 Correlation between field testing machine and load cell reading

4. CONCLUSIONS

This paper presented the results of a preliminary investigation on the development a new soil-cement block using produced water from oil-fields. The study reported the results of chemical and physical analyses on produced water and soil samples from Nimr and Marmoul oil-field sites. Chemical analyses measurements were total alkalinity, sulfate content, chloride content, total dissolved solids and water hardness, pH and conductivity, whereas, tests to determine the physical properties of the soil included specific gravity, Atterberg limits, shrinkage, and grading. The study found that the soil and water from Nimr and Marmoul oil-field sites are suitable for production of compressed blocks. Since the percentage of clay in the two soils is small, cement can be used as stabilizer for the two soils. The quantity of the stabilizer has to be determined by studying different mixes containing various cement proportions. The study concluded that it is possible to produce soil-cement blocks with good mechanical properties using local soil in Oman.

5. ACKNOWLEDGEMENTS

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