Journal of Engg. Research Vol. 8 No. (1) March 2020 pp. 128-138

Assessment of the suitability of Kuwait oil-contaminated sands for beneficial reuse

Waleed Abdullah*, Masoud Janbaz**, Robert Miskewitz***, Lauren Iacobucci****, Kelly Francisco*****, Waleed Khaled Eid****** and Ali Maher*******

*Assistant Professor, Kuwait University, P.O. Box 5969, Safat, 13060 Kuwait
**Postdoctoral Associate, Rutgers, the State University of New Jersey, ORCID: 0000-0002-6613-5587, 100 Brett Rd, Piscataway, NJ 08854, USA
***Associate Research Professor, Rutgers, the State University of New Jersey, 100 Brett Rd, Piscataway, NJ 08854, USA
****Research Assistant, Rutgers, the State University of New Jersey, 100 Brett Rd, Piscataway, NJ 08854, USA
*****Postdoctoral Associate, Rutgers, the State University of New Jersey, 100 Brett Rd, Piscataway, NJ 08854, USA
******Assistant Professor, Kuwait University, P.O. Box 5969, Safat 13060, Kuwait
*******Professor, Rutgers, the State University of New Jersey, 100 Brett Rd, Piscataway, NJ 08854, USA
*Corresponding Author: waleed.abdullah@ku.edu.kw

ABSTRACT

The purpose of this study was to investigate the potential beneficial use of the oil-contaminated sand of Northern Kuwait as a construction material. Samples were created with three Portland cement contents (4, 8, and 10% by weight of sand) and three different organic contents (9, 21, and 33%), cured for seven days and tested for unconfined compressive strength, moisture content, and organic content. The early strength evaluation of stabilized material is an important factor in landfill caps and construction fill beneficial use applications to provide necessary strength for machinery operations. The results of this research show that the Portland cement content has a direct relationship with strength gain in the oil-contaminated sand. The oil within the soil matrix inhibits the Portland cement hydration reactions and adversely affects the strength gain of stabilized material. Ultimately, the results of this study show that 8% Portland cement, of the total weight of the soil, mixed in the form of a slurry with 1:1 or 2.5:1 (water weight: cement weight) can fulfill the strength requirement for beneficial reuse of the oil-contaminated sand.

Keywords: landfill; oil-contaminated sand; organic content; Portland cement; unconfined compressive strength.

INTRODUCTION

During the 1990-1991 Gulf War, 605 oil wells in Kuwait were damaged and/or set on fire (Deeter, 2011). As a result, a large volume of oil was discharged onto the land surface. This resulted in the formation of approximately 300 large oil spill lakes, which covered 0.65% of the entire surface area of the country and remained to this day. These oil lakes vary in their type of contaminants, surface area, penetration depth, and the level of contamination (Abdullah et al., 2014). According to Elgibaly (1999), the volume of Kuwaiti desert sand contaminated by oil is approximately 18 million cubic meters. Based on the oil fields, Kuwait is divided into two major geographic regions, Northern and Southern (Figure 1). In the southern region, oil lakes are typically wet, consisting of a pool of viscous liquid oil sludge overlying the oil-contaminated soil, whereas oil lakes in the northern region are typically dry, consisting of black, relatively hard, dry contaminated sandy soil grains covered with a dark brown oily residue. For this study, the focus was on the material from the northern region of Kuwait. These oil lakes have a significant environmental impact in Kuwait and should be remediated. Individual efforts tried to decontaminate the soil with only partial successes. Thereafter, a joint project between the United Nation Compensation Commission (UNCC), Kuwait National Focal Point (KNFP), and Kuwait University (KU) has been initiated to conduct a comprehensive work to eliminate the contaminated soil and its environmental impacts (AlDuwaisan and AlNaseem, 2011). Several technologies have been assessed for mitigating oil contamination throughout the impacted areas of Kuwait. These include sand washing, bio-remediation, and electrokinetic sand remediation. Although technically feasible, none of these technologies are considered to be cost-effective (Lim et al., 2016, Riser, 1998). One potentially low-cost remedy is to stabilize this material with Portland cement and reuse it as a landfill cap or low strength construction fill. This approach can reduce the material environmental impact and can be more cost-effective as the resulting material has a commercial value, which can offset some of the costs of treatment (Abousnina, 2015).

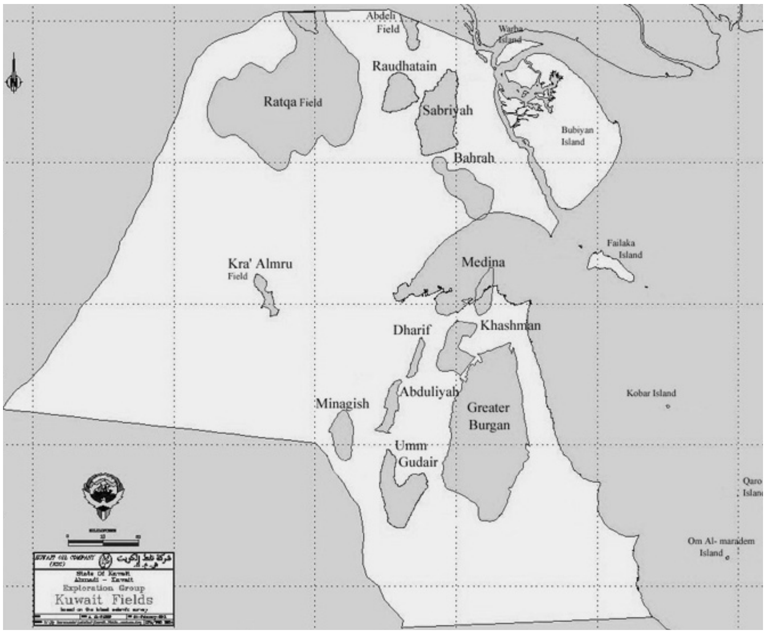

Figure 1. Distribution of oil lakes in Kuwait.

Several researchers have studied the potential application for oil-contaminated sand in asphalt concrete for use in secondary roads (Al-Mutairi & Eid, 1997) or as building construction material (Abousnina et al., 2015 and 2016, Oluremi and Osuolale, 2014). Generally, soils with high organic content have a less binding capacity. It is well known that the presence of organic matter modifies the geomechanical behavior of the soil (Stevenson, 1994) and may interfere with the hydration process as it has the potential to coat soil grains, which inhibits the hydration reactions (Kamon et al., 1989). The Kuwait oil-contaminated sands investigated for this study were dry, oil-stained sands obtained from the northern oil lakes. The oil covers most of the surface of the grains and, thus, reduces the available surface area of soil grains to be bound during the hydration of Portland cement within the stabilized matrix.

The purpose of this study was to determine the geotechnical suitability of Kuwaiti oil-contaminated sands stabilized with Portland cement for use as a landfill cap or low strength construction fill material. The desert environment typical of Kuwait results in very low moisture content in the soil samples. In order to effectively mix the oil sands with the binder, Portland cement is added as a slurry. This ensures the workability of the processed material as well as strength required, for civil engineering applications.

METHODS AND MATERIALS

Sample collection and index properties

The soil in this study was obtained from dry oil lake in northern Kuwait. Upon visual inspection, the soil sample collected was a non-homogenous mixture of sand and oil residue (Figure 2). The bulk of the sample was loose sand and oil mixture with an average organic content of 9%. The oil residue in the sandy soil caused a portion of the sand to stick together in the form of ‘clumps’. These clumps varied in size and the amount of oil residue within the clump itself. The oil residue/sand clumps were removed from the remaining portion of the sample, crushed, and treated as a separate sample. The oil residue/sand clumps contained a high amount of oil residue, which was confirmed, via measurement of the organic content, to be 33%. In addition, a third sample was created via a composite of the raw sand of 9% organic content and the crushed clumps of 33% organic content, which resulted in a 21% organic content sand sample. Moisture content was determined for those samples taken from the sample bucket after breaking the clumps and mixing the material with hand tools until being homogenous. Index properties were evaluated for the collected soil sample according to the following ASTM standards (Table 1).

Figure 2. Sample collected showing a non-homogenous mixture of sand and oil residue 'clumps'.

Table 1. Index property test ASTM standards.

Test Type	ASTM Standard	Value
Atterberg's Limits (LL and PL)	ASTM D4318	NP
Specific Gravity of Solids (G_s)	ASTM D854	2.45
Organic Content	ASTM D2974	9, 21, and 33%
Natural Water Content (w_n)	ASTM D2216	1%
Bulk Density	ASTM D7263	1.26 (gr/cm^3)

Sieve analysis results and the soil classification, according to the Unified Soil Classification System (USCS), are presented in Figure 3.

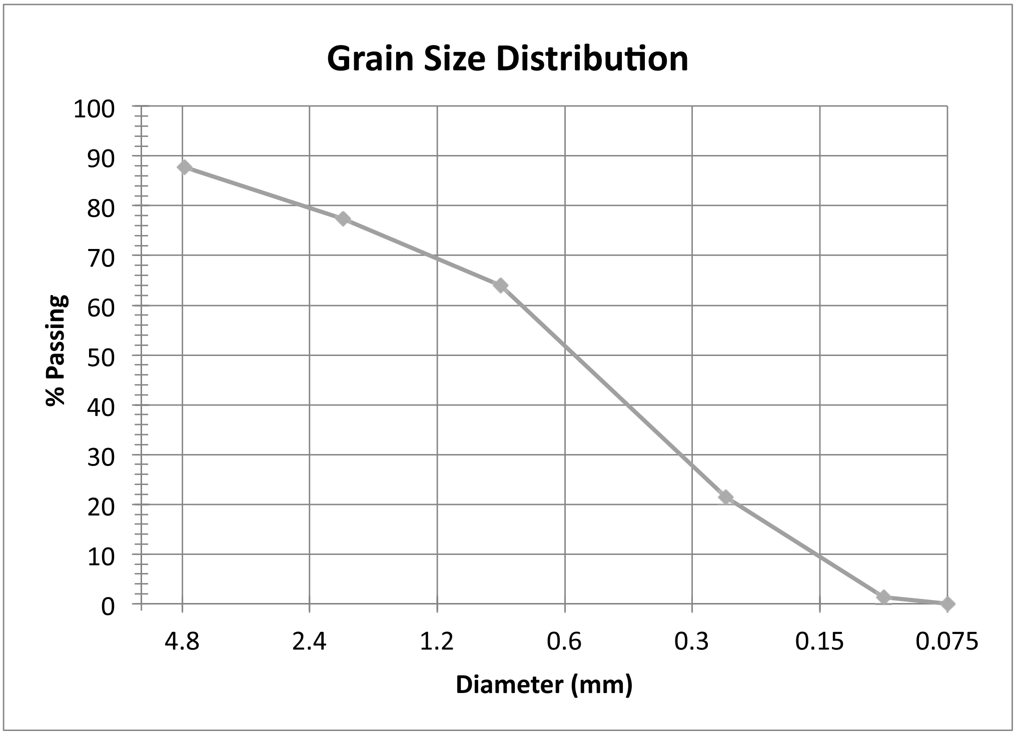

Figure 3. Sieve analysis curve.

According to the grain size distribution, the soil has a large portion of the medium to fine sand, more than 90% of the sediment passed through sieve #4 and was retained on Sieve #200 (Figure 2). Based on Unified Soil Classification System (USCS), the Coefficient of curvature C_c, is 1.02 and the coefficient of uniformity C_u, is 5.3, which classifies the soil as a well-graded sand with a small trace of gravel. The organic content of the sandy portion of the soil, passed through sieve #4 and retained on sieve #200, is 9%. The remaining material, which was retained on sieve #4, consisted of hardened clumps of organic material (oil) and sand. The clumps were crushed, passed through a #10 sieve, and then tested for organic content. The organic content of the crushed clumps was found to be 33%.

Sample preparation

Commercially available Quikrete Type I/II Portland cement (ASTM C 150 Type I standard) was used as a binder in this experiment. A series of ten mixing ratios were established to best identify the optimum ratio of cement and oil sand for adjusted organic contents (Table 2). Samples were made in triplicate and cured for 7 days at 20°C in Thermocure II water bath curing boxes (Construction Innovation Co. Inc.), to avoid temperature fluctuations. The mixture identification scheme is the percentage of cement followed by the slurry water to cement ratio (W/C) followed by the organic content of the oil sand. For example, ‘4C-5-9’ represents a mix with 4% Portland cement by wet weight of the soil, 5 to 1 water to cement ratio, and 9% organic content.

Table 2. Experimental mixing conditions.

Mixture ID	Total Binder (% wet weight of soil)	Water to Cement Ratio	Organic Content (%)
4C-2.5-9	4.0	2.5 to 1	9
4C-5-9	4.0	5 to 1	9
4C-8-9	4.0	8 to 1	9
8C-1-9	8.0	1 to 1	9
8C-2.5-9	8.0	2.5 to 1	9
8C-1-21	8.0	1 to 1	21
8C-2.5-21	8.0	2.5 to 1	21
8C-1-33	8.0	1 to 1	33
8C-2.5-33	8.0	2.5 to 1	33
10C-2.5-9	10.0	2.5 to 1	9

The purpose was to study the impact of organic content (oil residue) on strength gain to produce material that can be beneficially reused, potentially in a secondary road base or as a construction fill application. Three batches of oil residual contaminated soil samples were prepared with a range of organic contents. The soil sample collected on-site in Northern Kuwait was a non-homogenous mixture of sand and oil residue. The first mix was sand with 9% organic content. The second mix was made from crushed sand with 33% organics. The third mix was created by mixing equal masses of 9% and 33% organics sand, which resulted in a 21% organic content sand sample. To prepare the samples, approximately 1.6 kg of soil was measured into a 1-gallon mixing bucket. Based on the mixing condition, corresponding amounts of cement and water were mixed with the sandy sample. Mixing continued until the operator was visually confident in the homogeneity of the mixture (EuroSoilStab, 2002).

Once mixing was complete, a sample of the material was taken to determine its post-mixing moisture content and then three samples were created for strength evaluation in 7 days. Samples were created using plastic cylindrical molds with 2-inch inside diameter and 4-inch height. The creation of samples followed the Japanese Geotechnical Society Standard, by Kitazume (2017). Molds were filled with the mixture in three layers and compacted using the tapping technique addressed in a molding procedure study by Kitazume (Kitazume et al., 2015). The purpose of tapping is to ensure that air bubbles are removed from the mixture. Prepared samples were then stored inside the temperature controlled curing boxes.

Testing procedure

Unconfined compressive strength (UC) tests were performed on all the samples after a curing time of 7 days. According to Kearney et al. (1999), heavy truck trafficking is allowed only after sufficient curing time, usually 7 days on a completed soil-cement road base after compaction. The testing procedure followed ASTM D2166 using an ELE Tritest50 device. The device's strain rate was set to 1%/min and strength, and strain data were recorded electronically using ELE software. Moisture content samples were also taken immediately following UC tests (upon the completion of curing). Water content was determined via the method described in ASTM D2216-10.

RESULTS AND DISCUSSION

Moisture content was calculated for each sample as the ratio of the mass of water in the sample over the mass of dry solid soil particles (Figure 4). Since the presence of free water in the stabilized soil matrix reduces the overall rigidity of the samples, those containing the smallest amount of water are often found to be the strongest given the same amount of pozzolan additive (Ribeiro, 2016, and Consoli, 2011). Mix '8C-1-9' shows less moisture content in its matrix and has smaller organic content compared to other mixes with 8% binder content. As a result, it is expected to provide the greatest strength gain. In contrast mix '4C-8-9' shows the highest water content and lowest amount of pozzolan in its matrix and is expected to be the weakest mix of all.

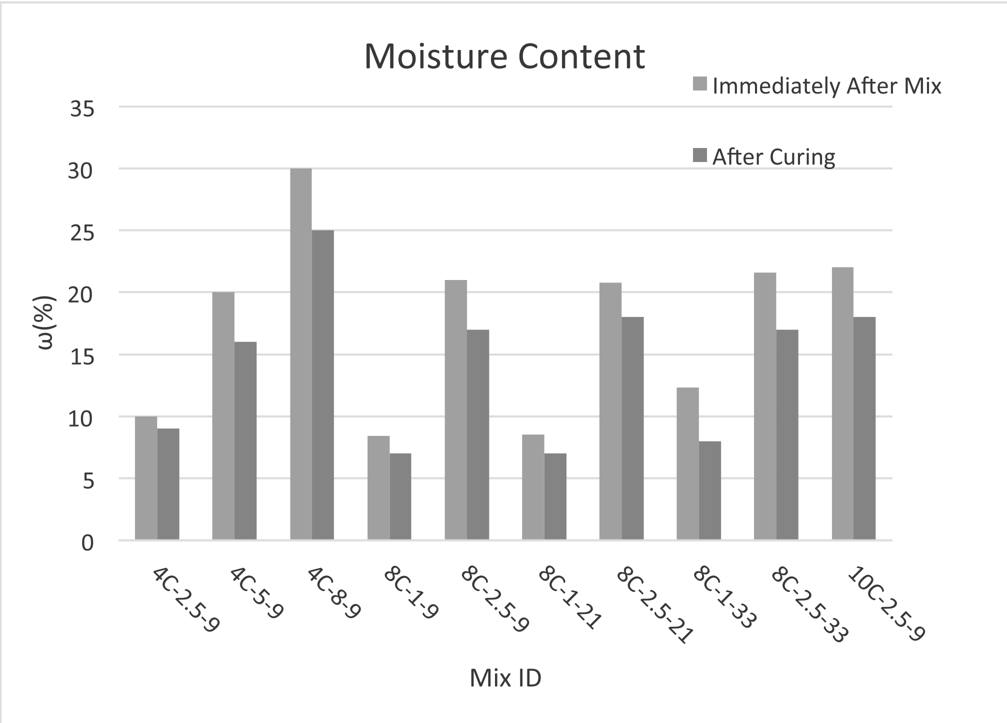

Figure 4. Average moisture content of samples.

UC Strength – Overview

Early strength evaluation shows that greater amounts of Portland cement used to stabilize the sample will create stronger samples. However, it is apparent that increasing organic content in the soil will negatively affect the strength gain (Figure 5). As discussed earlier, the organic content (oil residue) had a pronounced coating effect that inhibited the hydration of the cement and, in turn, resulted in lower unconfined compressive strength (Trembley, 2002, Wong, 2008, and Baker, 2015). Figure 5 presents the results of all unconfined compressive strength tests, for all of the samples cured at 20°C for 7 days.

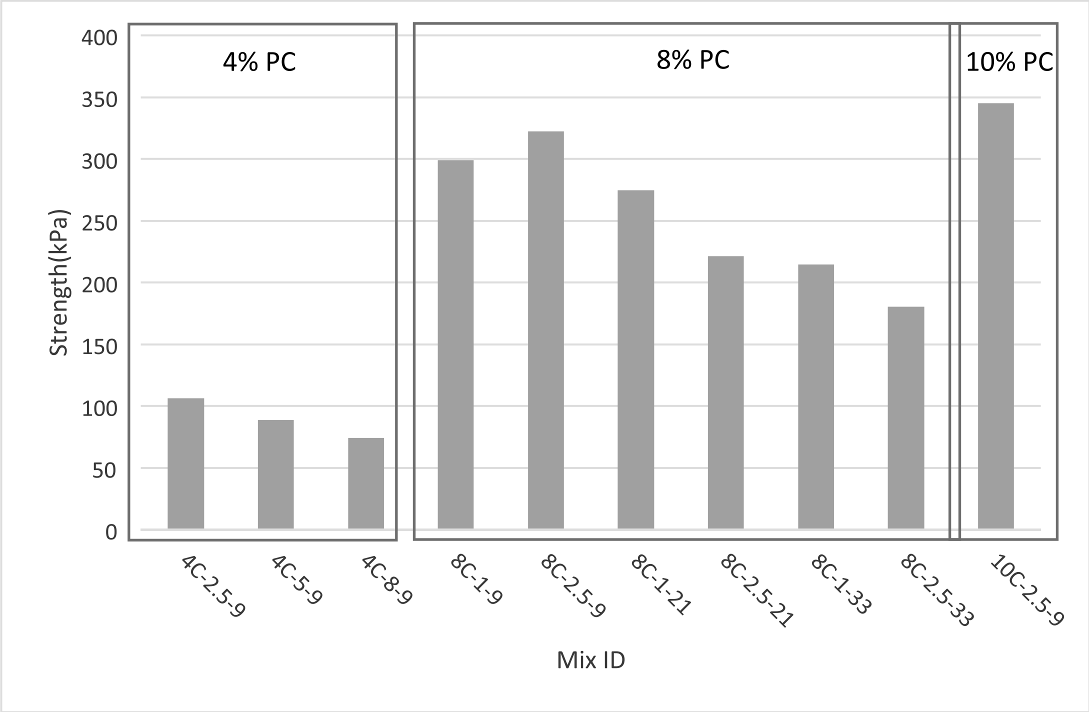

Figure 5. Unconfined compressive strength of stabilized soil at different cement content.

A comparison of moisture content (Figure 4) and unconfined compressive strength (Figure 5) reveals there is a direct relationship between the moisture content after mix and strength. In fact, a smaller amount of free water inside the mix results in better strength qualities. In particular, mix '8C-1-9', which has one to one water to cement ratio (W/C), has approximately the similar strength as mix '8C-2.5-9' in which the ratio of W/C is 2.5 to 1. This indicates a slight difference in the strength of the mix with more water to cement ratio. However, further statistical analysis (t-test) for the difference in the mean of the two data sets with equal variance and a critical P value of 0.05 did not reveal a significant difference (P value >0.05) (Table 3). Therefore, there is not enough evidence to conclude a difference in the mean strength value of mix '8C-1-9' and '8C-2.5-9'. The same statistical test for other mixes showed a significant difference between the mean of the strength for groups with different W/C ratio (P Values <0.05).

Table 3. T-Test Results for the difference in the mean of the two data sets (8% Portland cement).

P-Value (Target=0.05)		
8C-1-9	>0.05	no significant difference
8C-2.5-9		
8C-1-21	<0.05	significant difference
8C-2.5-21		
8C-1-33	<0.05	significant difference
8C-2.5-33		

The minimum amount of water to cement ratio to have a complete cement hydration process is about 0.45, according to ACI 318. The result of T-test for comparing the two mean with different variances and a critical P value of 0.05 indicates that the 4% and 8% Portland cement mixes and 8% and 10% Portland cement mixes revealed a significant difference between the average strength values (both P values >0.05). Therefore, there is enough evidence to conclude that there is a significant difference in strength of mixes prepared with different dosage of Portland cement at 7 days of curing.

Figure 6 is similar to Figure 4 and shows the organic content effect on the strength gain. Increasing organic content has an adverse effect on strength gain in case of similar pozzolan content. The results of single factor Analysis of Variance (ANOVA) for the difference in the mean value of strength between mixes with the same Portland cement content and water to cement ratio showed a significant difference between different organic contents. The statistical analysis revealed that there is enough evidence to conclude that higher organic content results in lower strength gain at the same pozzolan content. Retardation of cement hydration reaction and prevention of binding by coating the specific surface of the soil particles are two major important factors in this case (Trembley, 2002 and Baker, 2015).

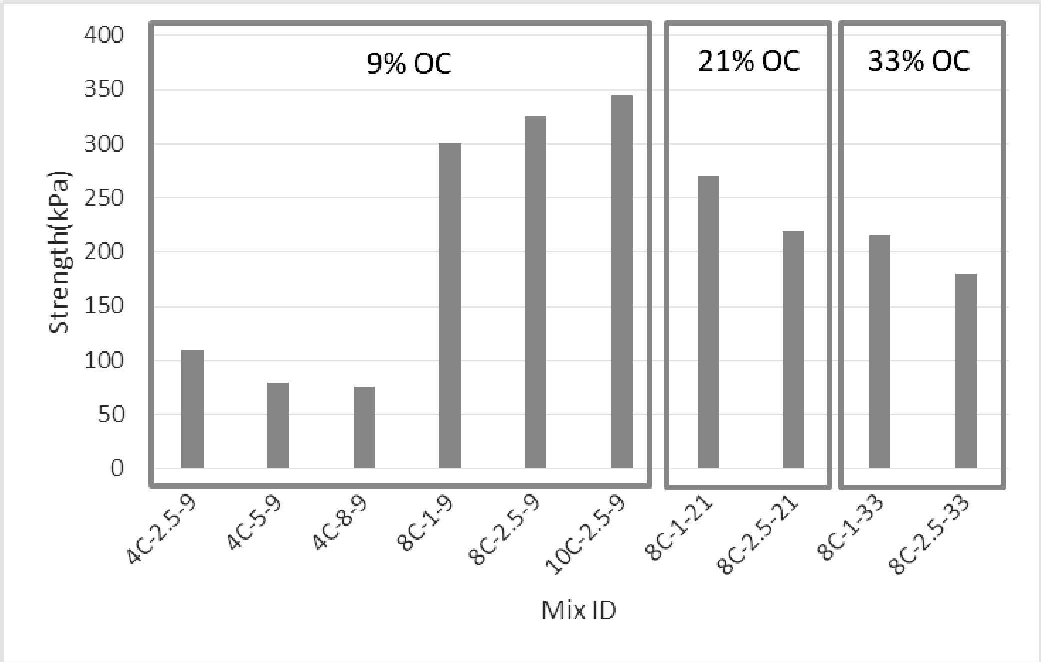

Figure 6. Unconfined compressive strength of stabilized soil at different organic contents.

Federal Highway Administration Research and Technology (FHWA) requires the maximum unconfined compressive strength of 300 psi (2068 kPa) for Controlled Low Strength Material (CLSM) at 28 days for most current applications. Strength specification for landfill caps and fills requires 1000 to 2000 psf (48 to 96 kPa), within 2 to 3 days after placement (Maher et al., 2013). The early strength data of this research shows that 8% Portland cement, of the total weight of the soil, mixed in the form of a slurry with 1 to 1 or 2.5 to 1 can fulfill the requirement to be used as controlled low strength fill material or it can be used as final cover material in the remediation and closure of landfills caps applications.

However, the General Specifications for Kuwait Motorway/Expressway System, Ministry of Public Works, State of Kuwait (August 2004), do not include any provision for CLSM. In fact, the only reference specified is for Concrete class E to be used as back fill material (section 208.06.3). Class E concrete should have a minimum crushing strength based on work test cubes at 28 days of 70 kg/cm^2 (6800 kPa), and a minimum cement content of 180 kg/m^3 (section

502.01). By adapting the use of the proposed mix for CLSM in Kuwait, it will reduce the amount of Portland cement in the mix as well as utilize the huge surplus oil-contaminated soil in the construction industry.

CONCLUSIONS

In this study, strength gain of an oil-contaminated sandy soil from Northern Kuwait mixed with Portland cement at different dosages was studied. The mix design was structured based on three cement dosages (4, 8, and 10% by wet weight of sand) mixed with three soil samples with organic contents (9, 21, and 33%). Samples were cured for seven days and tested for unconfined compressive strength, moisture content, and organic content.

Overall, it was observed that the increase in organic content has an adverse effect on strength gain of the oil-contaminated sandy soil. This can be attributed to the fact that the type of organics (crude oil) impedes cement hydration and reduces the strength gain. Also, the increase in dosage of Portland cement has a direct relationship with the increase in strength of the solidified soil.

This study showed that 8% Portland cement mixed in the form of slurry with 1:1 and 2.5:1 (water weight: Portland cement weight) can produce a product to be used beneficially for landfill covers or Controlled Low Strength fill material.

ACKNOWLEDGMENT

The authors express their appreciation to Mishari Al-Bader, Senior Engineer Project, Soil Remediation Group, KOC, Abdullah AlKandari, Senior Engineer Project, Soil Remediation Group, KOC, and DJamel Lekmine, Manager Technical Services, Worley Parsons, for their assistance and effort in collecting the contaminated soil samples from the field.

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Submitted: 26/09/2018
Revised: 11/07/2019
Accepted: 14/07/2019

تقييم مدى ملاءمة الرمال الكويتية المُلوثة بالنفط لإعادة استخدامها بشكل مفيد

*وليد عبد الله، **مسعود جانباز، **روبرت ميسكويتز، **لورين إيكوبوتشي، **كيلي فرانسيسكو، *وليد خالد عيد و**علي ماهر
*جامعة الكويت، الكويت
**جامعة ولاية نيو جيرسي، بيسكاتواي، نيو جيرسي، الولايات المتحدة الأمريكية.

الخلاصة

الغرض من هذه الدراسة هو الكشف عن امكانية استخدام الرمال المُلوثة بالنفط في شمال الكويت كمواد للبناء. تم تجهيز العينات بثلاثة محتويات من الأسمنت البورتلاندي (4 و 8 و 10% من وزن الرمال) وثلاثة محتويات عضوية مختلفة (9 و 21 و 33%)، وتم معالجتها لمدة سبعة أيام واختبارها من حيث مقاومة الانضغاط غير المحصور ومحتوى الرطوبة والمحتوى العضوي. يُعد التقييم المبكر لمقاومة المواد المستقرة عامل هام في أغطية مدافن النفايات وتطبيقات البناء لتوفير المقاومة اللازمة لتشغيل الآلات. تُظهر نتائج هذا البحث أن محتوى أسمنت بورتلاند له علاقة مباشرة باكتساب المقاومة في الرمال الملوثة بالنفط. يعمل الزيت الموجود في التربة على منع تفاعلات ترطيب الأسمنت البورتلاندي ويؤثر سلباً على زيادة مقاومة المواد المستقرة. وفي النهاية، أظهرت نتائج هذه الدراسة أن 8% من أسمنت بورتلاند، من إجمالي وزن التربة، مخلوط في صورة ملاط مع 1: 1 أو 2.5: 1 (وزن الماء : وزن الأسمنت) يمكنه تلبية متطلبات المقاومة لإعادة استخدام الرمال الملوثة بالنفط بشكل مفيد.