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Oil contaminated sand: An emerging and sustainable construction material

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Abstract

Crude oil spillage severely impacts the environment and affects the physical and chemical properties of the surrounding soil. Due to prohibitive cost of cleaning and disposing oil contaminated sand, mixing and stabilising them with cement and using them in construction is now considered as an alternative and cheap remediation method. In this paper, the effect of oil contamination on the mechanical properties of sand and its concrete were reviewed. In addition, the results of the on-going research and development on the effects of light crude oil contamination on the properties of fine sand and the produced mortar are presented. For fine sand contaminated with light crude oil, it was found that the cohesion increased significantly up to 1% of oil contamination and then decreased with increasing percentage of crude oil while a slight reduction in frictional angle was observed with oil contamination. The highest compressive strength was obtained for mortar with 1% oil contamination and with only a 18% decrease in strength of mortar with 10% oil contamination compared to the uncontaminated samples. More importantly, the compressive strength of mortar with oil contaminated sand was found suitable for some engineering applications indicating their high potential and beneficial use as an emerging and sustainable material in building and construction.

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Keywords: Crude oil, contamination, remediation, sustainable

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1. Introduction

There is growing public concern about the wide variety of toxic organic chemicals that are either deliberately or inadvertently being introduced into the environment. Petroleum hydrocarbons are a common example of these chemicals because they enter the environment frequently, in large volumes, and in a variety of ways. Leakage from natural deposits is one of the major ways that crude oil affects the environment [1]. Produced water associated with the production of oil and gas is also another source of oil contaminated sand [2-4]. Intentionally or accidentally, oil spill contamination impacts on the properties of the surrounding soil and changes its physical and chemical properties [2]. To minimize its effect to the environment, different methods of remediation ranging from sand washing, bio-remediation, electro-kinetic sand remediation, and thermal desorption have been implemented, but none are considered to be cost effective [5]. One alternative remediation method of by using the oil contaminated sand for engineering applications. As a result, some researchers have investigated its potential use and concluded that sand contaminated with oil can be used as road base materials or topping layers in parking areas [6-8]. Although these applications are considered to be a clever and successful solution in terms of cost and reducing the environmental impact, a better understanding on the mechanical properties of oil contaminated sand and its produced mortar/concrete is needed as this is a critical step before this material can be considered an emerging and sustainable material in building and construction.

Several studies on the mechanical properties of oil contaminated sand have already been conducted [9] and found that the properties such as cohesion, compaction, California Bearing Ratio (CBR) maybe enhanced to some extent of oil contamination but the permeability friction angle, optimum water content, and Atterberg limits generally decreased. However, it was also suggested that crude oil pollution is not identical in terms of its effect, and is affected by factors [10] and the extent to which crude oil affects the chemical composition and properties of sand varies from place to place which may lead to different results [11]. In order to determine its potential use in construction, several studies investigated on how oil contaminated sand would affect the mechanical properties of concrete; for example, the effect of “used” engine oil on the properties of fresh, hardened and reinforced concrete was investigated by Hamad and Rteil [12]. These investigations revealed that the engine oil acted like a chemical plasticizer and improved the fluidity and doubled the slump of the concrete mix, while maintaining its compressive strength. A similar study was conducted by Mindess and Young [13] where oil engine was added to a fresh concrete mix and they found that the effect was similar to adding an air-entraining chemical admixture that enhances some of the durability properties of concrete. Additionally, the potential use of soil contaminated with petroleum in highway construction was investigated by Hassan et al. [14], wherein they concluded that the material could be used for this purpose. In a recent study by Ajagbe et al. [3] they investigated the effect of crude oil on compressive strength of concrete, and concluded that 18 to 90% of its compressive strength was lost due to 2.5 to 25% contamination with crude oil. Abdul Ahad [15] indicated there was a significant reduction in the compressive strength and about 11% reduction in the splitting-tensile strength of concrete soaked in crude oil. However, most of these researchers disagree on the effect of crude oil on the engineering behavior of sand. Thus, there is a need to further investigate the properties of oil contaminated sand and its effect on produced mortar and concrete.

This paper presents the effect of light crude oil contamination on the mechanical properties of fine sand and the produced mortar, which are the results of the ongoing research and development activities of the authors. In addition, an evaluation and identification of the beneficial use of oil contaminated sand in engineering and construction is presented.

2. Mechanical properties of fine sand contaminated with light crude oil

Light crude oil is considered to be one of the most adverse environmental issues compared to medium and heavy crude oil because it can easily penetrate and migrate through sand particles. Moreover, this is the main causes of contamination in the Libyan desert, where the first author originated. On this basis, the effect of light crude oil contamination on the important properties of fine sand related to construction was investigated such cohesion, friction angle and shear strength. In this investigation, the samples were prepared by mixing dry sand with different percentages of light crude oil (0, 0.5, 1, 2, 4, 6, 8, 10, 15 and 20%) by the weight of the dry sand. The direct shear test for oil contaminated sand was then conducted using the ShearTrac-II system under constant vertical loading and according to AS 1289.6.2.2—1998 [16].

2.1. Cohesion of oil contaminated fine sand

Figure 1 shows that there was a significant increase in cohesion (c) from uncontaminated (0%) to sand with 1% oil contamination, which has the highest cohesion at 10.76 kPa. The cohesion then decreased when the percentage of crude oil contamination increased. This increase was reasonable because the moisture content of the dry sand used in these experiments was zero, so the addition of 1% of crude oil increased its wetness and cohesion between the particles of sand (Figure 2 shows the microscopic observation of these particles). With the uncontaminated (0%) sand, the loose status of the particles are shown in Fig. 2-a, while Fig. 2-b shows how up to 0.5% of crude oil increased the cohesion between the particles, and gathered them together. Cohesion was highest with a 1% addition of crude oil, and as Fig. 2-c shows, the larger particles adhered to the smaller particles, however with 2% of crude oil added, cohesion occurred but as Fig. 2-d shows, the particles themselves became covered with oil. The lowest amount of cohesion of 1.82 kPa was measured in fine sand with 20% of oil contamination.

The trend towards cohesion that was observed in this study agreed with the findings observed by Cokca et al. [17] which indicated that the cohesive component of shear strength attained its peak value at an optimum moisture content and then decreased as the amount of oil increased. On the other hand, the reduction in cohesion with the further addition of light crude oil was attributed to the particles of sand being coated with crude oil which reduced the interaction between them, as shown in Figure 3. At 4% contamination with crude oil the particles became coated with oil and became slippery, which decreased their cohesion, as shown in Figure 3-a. Increasing the amount of crude oil from 4 to 10% resulted in a similar saturated state where the particles became even more slippery and even less cohesive, as Figure 3 b-d shows. However, Figure 4 a-b shows that the saturated status was apparent when the amount of oil was increased up to 15 and 20%, and there was even less cohesion.

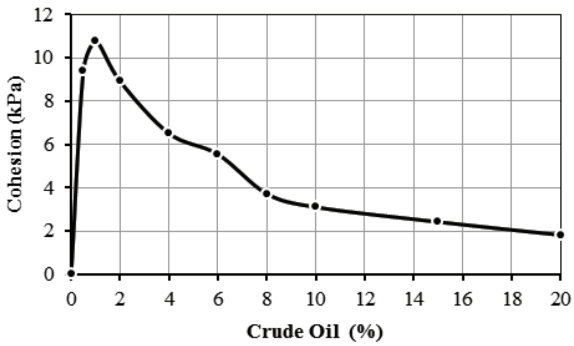

Figure 1: Cohesion as a function of crude oil contamination percentage (%)

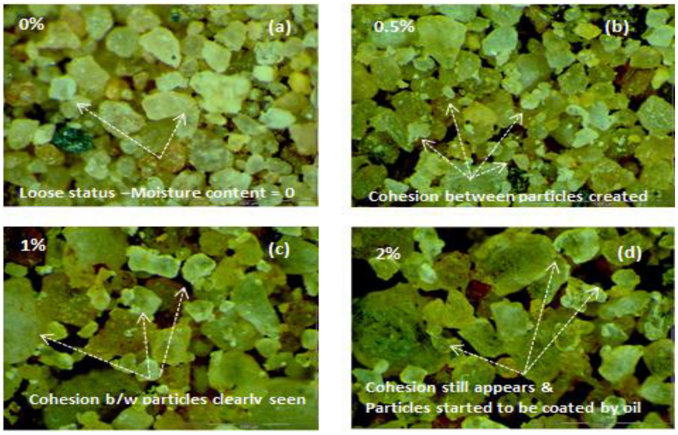

Figure 2: Images of fine sand with different percentages of contamination (0 to 2%)

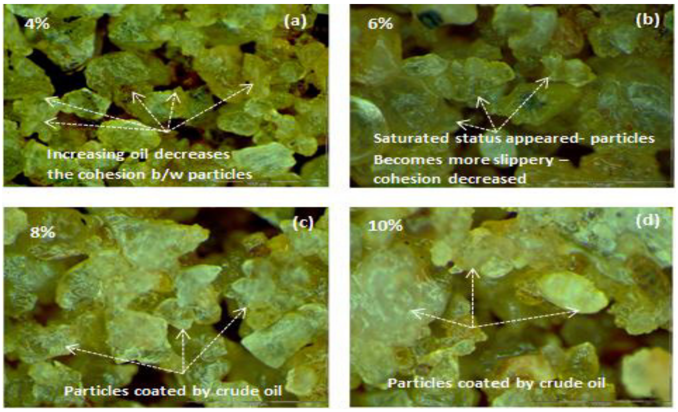

Figure 3: Images of fine sand with different percentages of contamination (4 to 10%)

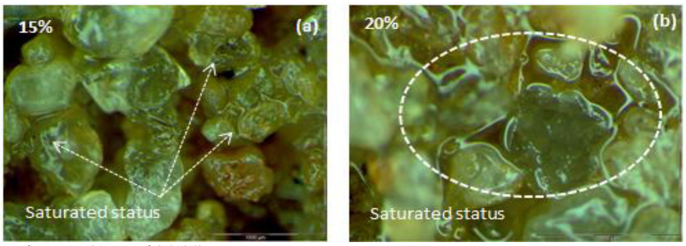

Figure 4: Images of the saturated status (15 and 20 %)

2.2. Frictional angle of oil contaminated fine sand

Figure 5 illustrates the frictional angle of fine sand with different percentages of crude oil contamination. The results show a significant reduction in the frictional angle from uncontaminated (0%) to contaminated samples (0.5%) (from 38º to 31º). This reduction occurred because the crude oil acted as a lubricant that enabled the particles to slip and slide against each other; but crude oil products reduce the friction between the particles better, which decreases the space between them, and also reduces the frictional angle. However, there was no significant variation in the frictional angle of in those samples 2% to 20% of oil contamination, which indicated that above 2% the particles were coated with crude oil, as shown in Figures 3 and 4, which resulted in the same frictional angle. Thus, the decline in shear strength of sand contaminate with oil can be specified by the mechanical interaction caused by high pore fluid viscosity.

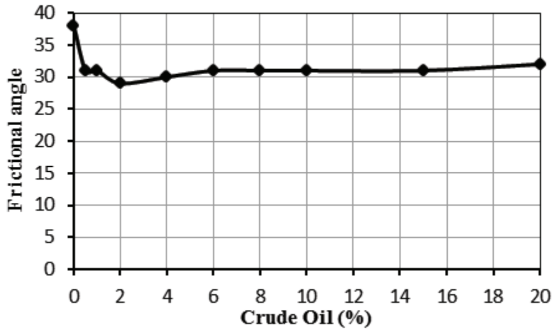

Figure 5: Frictional angle as a function of the percentage of crude oil contamination (%)

3. Compressive strength of mortar with contaminated fine sand

The compressive strength of mortar using fine sand with different levels of light crude oil contamination (0, 0.5, 1, 2, 4, 6, 8, 10, 15 and 20%) was investigated. The mortar was prepared following the recommendations of AS 2350.12-2006 [18] with mix proportions of 1 part of cement and three parts of sand (by mass), and a water cement ratio (w/c) of 0.50. Plastic moulds (50mm diameter and 100mm high) were used to avoid having to use any releasing agent or grease to remove the specimens. This also prevented any crude oil leaching from the mix. All the specimens were prepared at a room temperature of around 22 °C, while the curing was done in a fog room at 25 °C and 85% humidity for 28 days before being tested.

The compressive strength of the mortar with oil contaminated sand is shown in Figure 6. It can be seen that the highest compressive strength was 32.5 MPa, and this occurred in samples with 1% of crude oil contamination, while the lowest compressive strength was 3.9MPa for mortar with 20% of light crude oil. This reduction of compressive strength for high level of oil contamination agrees with the results of previous studies [19, 20] where they observed that crude oil affected the compressive strength such that it decreased as the amount of crude oil increased. This indicated that high percentages of crude oil affected or inhibited the hydration process. As Winter [21] indicated, cement and water react together during hydration such that when they are mixed in suitable proportions, the result is a solid mass of gel and crystalline material which binds the constituents of a concrete mix together. However, the oil contaminants may have interfered with these binder reactions and prevented or delayed the particles from becoming fully hydrated, as was also mentioned by Kostecki et al [22].

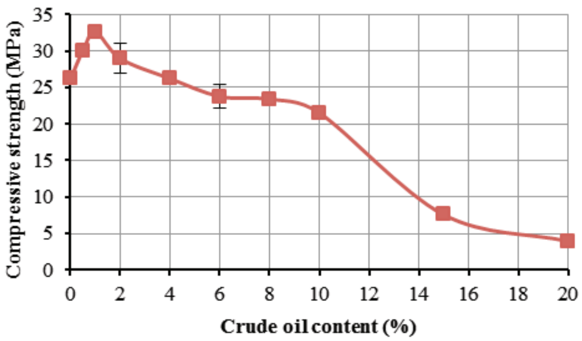

Figure 6: Effect of different crude oil content on the compressive strength

It is interesting to note that the compressive strength of mortar with sand contaminated by 0.5, 1, 2 and 4% of crude oil is at least same or even higher than the mortar with uncontaminated sand. The average compressive strength of these specimens was 30.1, 32.5, 28.9 and 26.2 MPa, respectively, while the compressive strength of uncontaminated sample (0%) was 26.2 MPa. This result was attributed to the degree of wettability caused by adding crude oil to dry sand which decreased the amount of water the sand could absorb as the sand particles is already in saturated surface dry condition. Abousnina et al [23] found that uncontaminated sand had the highest percentage of water absorption at 2.8%, but this percentage decreased as the amount of crude oil increased. With 0.5 % of crude oil, the water absorption was 2.3%, but with 1% of crude oil, water absorption decreased to 0.8%. However, water absorption was zero for sand with 2% of contamination and higher; this was due to the sand changing from dry to wet. Thus, all or most of the water added to the mix contacted the cement particles and helped complete the hydration process. Moreover, the results described in Section 3.3 regarding the effect that crude oil had on the shear strength of fine sand agreed with this finding, and also indicated that as the percentage of light crude oil increased up to 1% the shear strength also increased, but with more than 1% of contamination the shear strength began to decrease. This increase in the shear strength at low normal stress was due to the apparent cohesion observed in the sand, although the frictional angle decreased [23]. In addition, it can be seen that compressive strength up to 10% of crude oil contamination (21.5 MPa) is only 18% lower than the uncontaminated sand (26.2 MPa). This indicated that a higher compressive strength can be attained for contaminated sand than uncontaminated sand up to a certain level of oil contamination. These results have therefore indicated the potential for using oil contaminated sand in building and construction.

4. Discussion

Several researchers failed to agree about the effect of crude oil on the engineering behaviour of sand thus Rehman et al. [24] suggested that the mechanical properties of sand needs to be carefully evaluated and comprehensively understood when considering any re-use of this material. At the same time, the prohibitive cost of the currently available remediation methods resulted in most developing but oil producing countries to find a better and more cost-effective way of utilising oil contaminated sand in order to minimise their potential risks to humans and the environment. For these reasons, a number of studies have been carried to investigate the effect of crude oil contamination on the properties of sand, but their results indicated a lack of agreement that stemmed from the different types of crude oil contamination, the permeability of sand, sand properties, absorption, chemical composition and quantity of spillage [10, 11, 25]. Moreover, several researchers [3, 15, 26-28] mixed contaminated sand with cement and then use it in construction as an alternative and cheap remediation method, but there are very few studies that explain how crude oil affects the mechanical properties of sand and how it can be used safely as a sustainable material in construction.

The results of the preliminary studies by the authors point towards the sustainable use of fine sand contaminated with light crude oil for construction. The fine sand contaminated with 1% of light crude oil exhibited higher shear strength than the uncontaminated sand due to the apparent increase in cohesion between the particles. Similarly, the compressive strength of mortar prepared using fine sand with up to 4% of oil contamination is higher than the uncontaminated sample. Moreover, only a 18% reduction in compressive strength was found for mortar with 10% oil contamination than uncontaminated samples. However, when the amount of crude oil was increased from 10 to 20%, the compressive strength decreased significantly due to oil in the mix hinder the hydration of the cement. These results indicate that the compressive strength of contaminated sand can be increased and be higher than the uncontaminated sand by adding some amount of oil. Similarly, sand with a high level of oil contamination can be mixed with uncontaminated sand to enhance its mechanical properties.

The compressive strength of mortar with oil contaminated sand up to 10% (21.5 MPa) indicates that this material is suitable for building and construction. Similarly, the results indicated that even the mortar using fine sand contaminated with 15 and 20% of light crude oil (compressive strength of 7.5 and 3.9 MPa, respectively) can be used for low-load bearing engineering application such as landfill layering and production of bricks. According to the United States Environmental Protection Agency (USEPA) guidelines, the recommended compressive strength at 28 days for layering in the landfill disposal site is 0.35 MPa, and 1.0 MPa in France and the Netherlands [29], respectively, whereas the Wastewater Technology Centre (WTC), Canada [30] specifies a compressive strength of 3.5 MPa for a sanitary landfill. In addition, the British standard for precast concrete masonry units (BSI, 1981) prescribed to use a compressive strength of 2.8 and 7 MPa for blocks and bricks, respectively. A minimum of 4.5 and 15 MPa is however the requirement by the Department of Transport in UK for sub-base and base materials. This shows the high potential of oil contaminated sand as sustainable material in building and construction. However, understanding the physical and mechanical properties of contaminated sand and its effect on produced mortar and concrete is very important in order to determine their end-use application. Once achieved, this will potentially solve the issues of oil contamination in oil producing countries because the cost of this method will be cheaper compared to the existing remediation methods.

5. Conclusion

This paper reviewed the effect of crude oil contamination on the mechanical properties of sand and the produced mortar/concrete in order to evaluate their suitability as a sustainable material in building and construction. It focused on the results of the ongoing research and development on the effect that light crude oil contamination on the mechanical properties of fine sand and the produced mortar. The conclusions drawn from this study are as follows:

- There is a lack of agreement regarding the effects of hydrocarbon compounds on the properties and behaviour of sand and its cement/concrete. In general, the mechanical properties of oil contaminated sand decreased, but some important properties were enhanced up to some level of contamination.
- The shear strength of fine sand with 1% of light crude oil contamination is higher than the uncontaminated fine sand. This is due to the significant increase in cohesion but with only slight reduction in frictional angle.
- A higher compressive strength was achieved for mortar with up to 4% containing light crude oil contamination than the uncontaminated samples. This is due to the degree of wettability of the surface of the sand particles. By increasing the crude oil from 10 to 20%, the compressive strength decreased significantly and in this condition, the oil contamination in the mix hindered the hydration process of the cement.
- The properties of mortar with oil contaminated sand were found suitable for some engineering applications. Up to 10% of light crude oil contamination, the compressive strength is comparable to mortar with uncontaminated sand indicating this can be used as an emerging and sustainable material in building and construction

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