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Physical and mechanical properties of cement mortar containing fine sand contaminated with light crude oil

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Abstract

Oil contaminated sand resulting from oil leakage has continuously been a major environmental concern worldwide. This problem affects the physical and chemical properties of the surrounding soil. Due to prohibitive cost of the existing remediation methods for oil contaminated sand, mixing them with cement and using in construction is considered as a cheaper alternative. In this study, the effect of light crude oil contamination on the physical and mechanical properties of cement mortar was investigated. Fine sand with different percentages of light crude oil by weight ranging from 0% to 10% was mixed with Ordinary Portland cement and cured in a fog room. The compressive strength of the cement mortar was then determined at 7, 14 and 28 days. Results showed that the workability and the total porosity of the cement mortar increased as the amount of crude oil increases. Moreover, the compressive strength increased with the increasing curing time for all specimens. The cement mortar containing fine sand with 1% light crude oil exhibited the highest compressive strength, which is 18%, 30% and 17% higher than the uncontaminated samples at 7, 14 ad 28 days, respectively. Interestingly, the cement mortar with up to 2% oil contamination has higher compressive strength than the 0% oil contamination while increasing the crude oil content more than 2% and up to 10% cause a reduction in the compressive strength by 50%. Still, the strength properties of mortar with oil contaminated sand up to 10% are suitable for landfill layering and production of bricks results indicating their high potential and beneficial use as a sustainable material in civil engineering and construction.

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Keywords: Light crude oil, compressive strength, cement mortar, sustainable materials

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1. Introduction

Crude oil contamination in sand is considered as a significant source of waste materials in the environment [1]. This contamination is normally caused by oil leakage, pipelines vandalism, wars, drilling, exploration and production of crude oil, and oily produced water [2]. Due to prohibitive cost of the existing remediation methods for oil contaminated sand, mixing them with cement and using in construction is considered as a cheaper alternative [3]. Earlier studies showed that the properties of fresh and hardened concrete can be enhanced by addition of waste used as chemical admixture and additives [4]. While a number of researchers [2, 5, 6] suggested that mixing oil contaminated sand with cement is a clever civil engineering solution to reduce the remediation cost and environmental impact, there are very limited studies conducted to investigate the properties of contaminated sand and its concrete in order to substantiate their beneficial use in construction.

The successful use of crude oil contaminated sand as a construction material depends on the required properties of the produced concrete. Compressive strength of concrete, a vital element of structural design, is the most important mechanical property which characterizes the quality of the produced concrete. The strength depends upon many factors, e.g. quality and quantity of cement, water cement ratio (w/c) and aggregates; mixing; placing, compaction and curing and the presence of contaminants and their degree [2]. Among those factors the presence of contaminants and its degree is considered as one of the most important factors that affects the compressive strength of concrete. The presence of contaminant at high level does not only affect the appearance of concrete but also may affect the strength developed of concrete [7]. Thus, before it is considered as a sustainable material in building and construction further investigation was needed to evaluate the effects of oil contamination on the mechanical properties the produced cement mortar/concrete. This paper presents an investigation on the physical and mechanical properties of cement mortar containing fine sand with different levels of light crude oil contamination.

2. Materials and methods

2.1 Preparation of the specimens

Air dried fine sand, with particle size less than 2.36 mm, was used due to its similarity to sand in the Libyan Desert where the first author came from. On the other hand, mineral Fork w2.5 motor cycle oil was used because its density and viscosity are similar to light crude oil [8, 9]. The samples were prepared by mixing dry sand with different percentages of light crude oil (0.5, 1, 2, 4, 6, 8 and 10 %) by the weight of dry sand. In addition, uncontaminated (0%) sand was prepared as a control sample. These percentages were selected based on the previous investigation on the mechanical properties of fine sand contaminated with light crude oil [10]. The oil was mixed manually with the dry sand and then the samples were placed inside a plastic container for 72 hours to allow the mixture to attain a homogenous condition. A lid was placed on the plastic container to prevent the crude oil from evaporating during this period of incubation.

2.2 Preparing, Casting and curing

A total of 72 specimens covering three samples for each specimen type were prepared. All laboratory work was conducted at a room temperature around 22ºC. The indicative workability of the cement mortar was measured using NL 3016 X / 002 Flow Table Apparatus following the procedures specified in ASTM C1437-07 (2007). The cement mortar were then placed in plastic moulds (50mm diameter and 100mm high) and cured in a fog room (FR) set at 25 ºC and 85% humidity. The specimens were kept in the fog room until they are ready for testing. Figure 1 shows the protocol of sample preparation based on the AS 2350.12 [11]. The composition of the mortar was based on AS 2350.12-2006 [11] with mix proportions of 1 part cement and three parts sand (by mass).

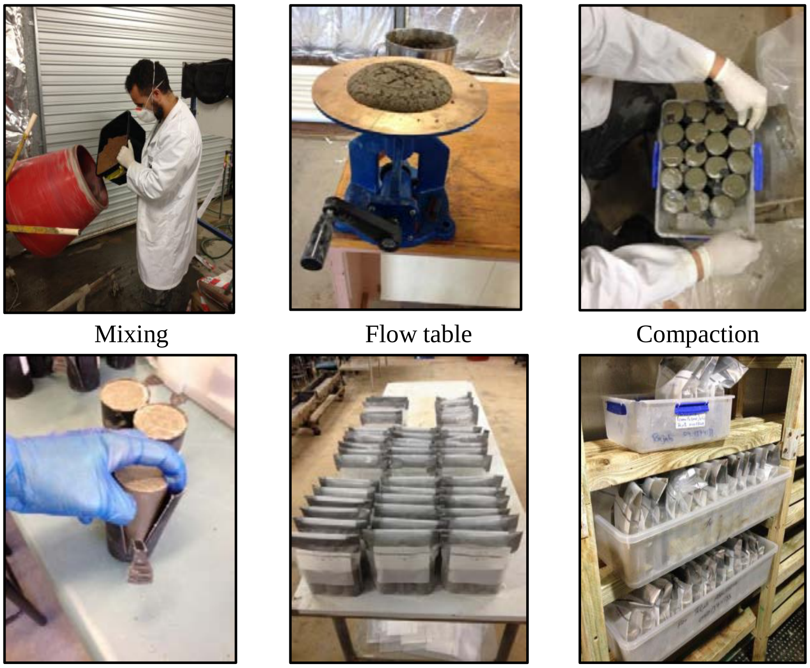


Figure 1 shows the preparation steps of mortar with light crude oil

2.3 Test Procedures

Compressive strength tests were carried out for all the specimens after 7, 14 and 28 days of curing. The specimens were tested to failure using a loading rate of 1.5 kN/min using 2 Channel Automatic Cube and Cylinder Compression Machine CT340-CT440 based on AS-1012.9 [12] as shown in Figure 2(ab). The compressive strength of the samples was calculated by dividing the failure load by the actual cross sectional area. Both ends of the cylindrical specimens were ground before being placed in the testing machine mainly to smooth their cross sectional surface areas also the rubber capping was used to apply the load uniformly to the specimens as shown in Figure 2(c). The porosity of each sample was determined by using TBitmap software [13]. The microstructure of all samples was characterised using a scanning electron microscope (SEM) (JEOL JCM-6000, Tokyo, Japan).

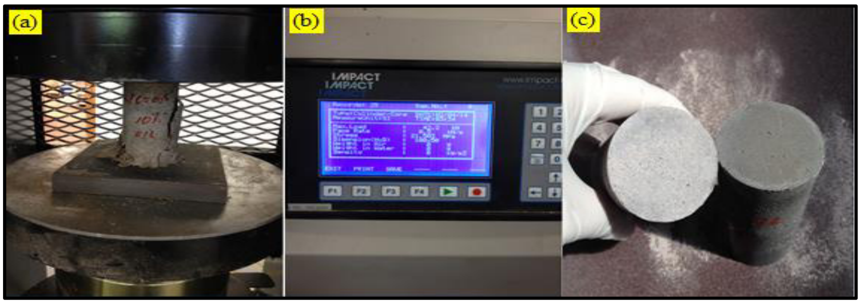


Figure 2: Compressive strength machine

3. Results and discussions

3.1 Effect of light crude oil on the flow

The flow table test was conducted based on the (ASTM C1437-07) as shown in Figure 3. The flow test results of the 0% up to 10% of crude oil contamination was 150 ±10mm. Increasing the crude oil content increases the workability which indicates that the crude oil works as a plasticizer agent. This agreed with a previous study conducted by Hamad and Rteil [14], where they concluded that the oil acted like a chemical plasticizer and improved the fluidity and doubled the slump of the concrete mix, while maintaining its compressive strength. Furthermore, the increase in flow for mixes containing light crude oil is a similar outcome of the other studies by Hamad, Rteil and El-Fadel [4] and Nuruddin, Shafiq and Beddu [15]. In addition, Al-Mutairi [16] indicated a good effect with regard to slump of concrete made from oil contaminated sand.

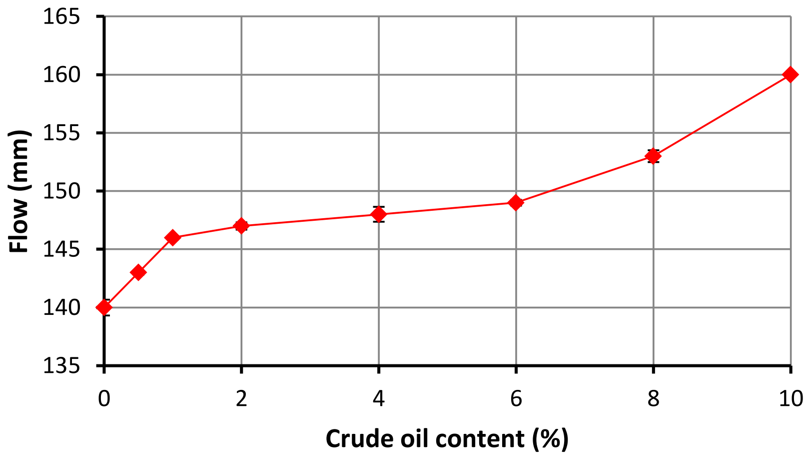


Figure 3: Flow values for mixes containing deferent percentage of light crude oil

3.2 Effect of crude oil contamination on the compressive strength

Figure 4 shows the compressive strength of mortar at different curing age (7, 14 and 28 days) as a function of crude oil content (0% to10%). It can be clearly observed that there was an increment of compressive strength for all specimens with advancement of hydration period (age). The cement mortar containing fine sand with 1% light crude oil exhibited the highest compressive strength, which is 18%, 30% and 17% higher than the uncontaminated samples at 7, 14 ad 28 days, respectively. Furthermore, the cement mortar with up to 2% oil contamination has higher compressive strength at the three different curing ages 7, 14 and 28 days by 3, 5 and 4.4% compared to uncontaminated sample (0%) while increasing the crude oil content up to 10% cause a reduction of the compressive strength by 50%. The increment of the compressive strength up to 2% compared to uncontaminated samples may rely to two main reasons. First, adding crude oil to the dry sand increases the wettability, and hence, the amount of water that the dry sand could absorb decreased. Thus, all or most of the water added to the mix contacted with the cement particles helped hydration process to be completed and hence, higher strength was obtained compared to uncontaminated samples. The second reason is the appearance of the cohesion status at these crude oil contamination levels, as it has been discussed and presented elsewhere in [17, 18].

On the other hand, the reduction of compressive strength for high level of oil contamination (from 2% to 10%) 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. 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].

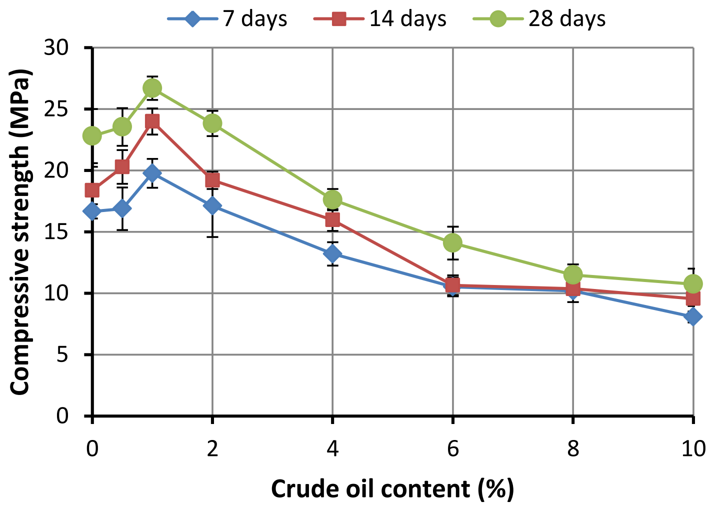


Figure: 4 Shows the compressive strength (MPa) as a function of different crude oil contaminations

Furthermore, Banfill and Saunders [23] studied the sorption of several organic compounds on to cement and related materials. They found that there was a poor correlation between retardation and the sorption of organic compounds on to unhydrated cement. The retardation correlated well with the sorption on to both hydrated cement and calcium hydroxide. This confirmed the theory of retardation based on both the hindered nucleation and growth of CH and the reduced permeability of the C-S-H around cement particles. According to Trussell and Spence [24] organic compounds retard or interfere with cement setting by the same mechanisms as described earlier. The most important difference however is that in most cases they do not form strong chemical bonds like most inorganic compounds do. Therefore their retention is strongly dependent on physical entrapment. Active carbon can be added to the cement matrix to bind organic contaminants [25]. However its presence during hydration causes extra porosity in the cement as it removes the water needed for the cement reactions.

3.3 Porosity and strength of mortar with light crude oil

The porosity of hardened concrete is an important property, which is an indicator of quality, strength and durability; it reduces with respect to the age as hydration processes [26]. The effect of porosity on the compressive strength was investigated under deferent percentages of light crude oil contaminations. Previous studies [27-29], indicated that the porosity plays a great role on the strength obtained, and hence, as the porosity increases the compressive strength of concrete decreases. The relationship between the total porosity of different percentage of crude oil during all curing ages presented in Figure 5. In general, it can be seen that the total porosity increased as the amount of crude oil increased but at the same time there is a decrease in the total porosity of all different of crude oil contamination (0% to10%) with advancement of hydration period. This may due to the gradual filling of large pore by hydration products of cementitious material [30, 31]. Figure 6 shows the hydration products created for cement mortar with 0 and 10% different crude oil contamination as observed under SEM. It can be clearly seen that the hydration products increases with the curing and fill the pores resulting in the decrease in the total porosity. The cementitious material was clearly observed at early curing age (7 days). The average reduction of the total porosity under different crude oil contamination at age of 14days compared to 7 day was 14%, while the reduction of the total porosity at 28 days was around 25% compared to 14 days.

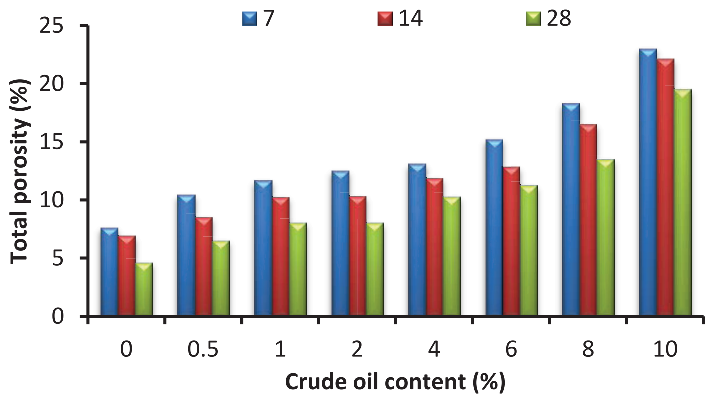


Figure 5 Total porosity as a function of different (%) of crude oil and curing age

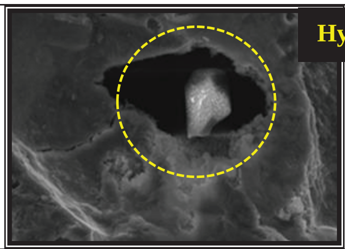
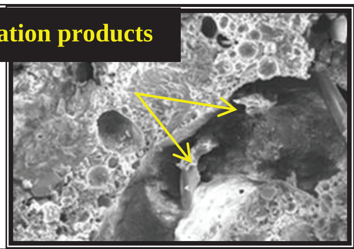
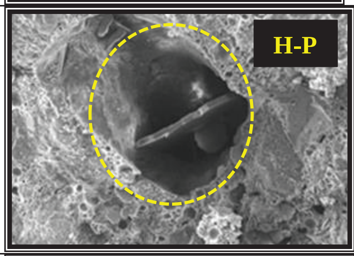
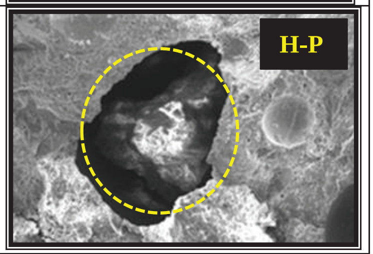
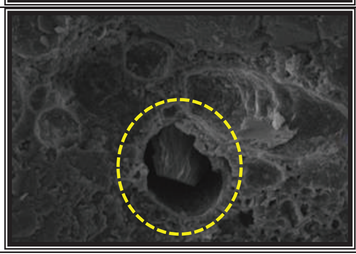
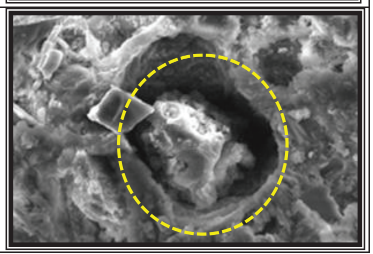
% / Age	0	10
7		
14		
28		

Figure 6 Shows hydration products of cementitious material

In spite of the fact that increasing the crude oil content affects total porosity with the different curing ages; the macroporosity (< 0.32 μm) was found the most effect of pores on the compressive strength as shown in Figure 7. The porosity was classified based on the pore size distribution microporosity, mesoporosity and macroporosity [32]. Several studies [33, 34] indicated that the compressive strength depends upon the amount of macroporosity and pore structure. Luping [35] found that a material with low porosity but more large pores may have a lower strength than a material with a higher porosity and less large pores. Consequently, the total porosity with the pore size distribution classification, microporose, mesopores and macropores was considered and calculated using the TBitmap software. As shown in Figure 7, microporosity (%) plotted as a function of different crude oil content (%). It can be seen that as the amount of crude oil content increased towards 1% of light crude oil, the total macroporosity decreased, while increasing the crude oil content from 2% up to 10% the total macropores increased. This agreed with compressive strength obtained as discussed in section 3.2.

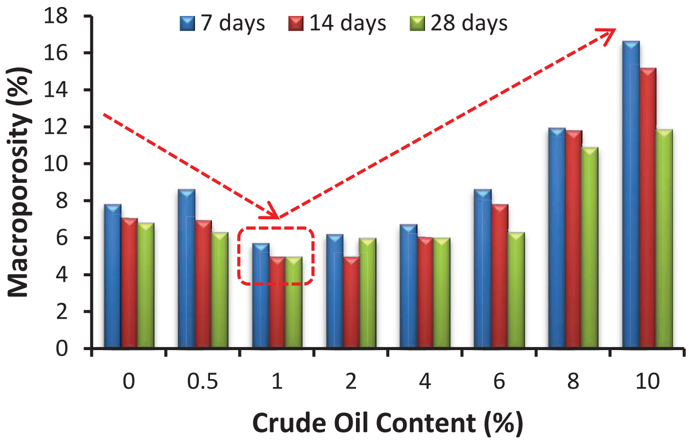


Figure 7 Show the macroporosity as a function of different crude oil content

4. Discussion

The results of this study showed high potential use of fine sand contaminated with light crude oil in construction. Under different curing age used (7, 14 and 28 days) the optimum compressive strength was observed at 1% of crude oil contamination. At this percentage (1%) higher compressive strength was conducted by 18%, 30% and 17% compared to uncontaminated sand. Furthermore, the cement mortar with up to 2% oil contamination has higher compressive strength at the three different curing ages 7, 14 and 28 days by 3, 5 and 4.4% compared to uncontaminated sample (0%). However, when the amount of crude oil increased up to 10%, the compressive strength decreased by around 50% compared to uncontaminated samples which may due to hinders the physical bond formation between cement paste and fine aggregate, which may due to insufficient of the hydration process.

This indicates that up to the certain amount of crude oil contaminated sand can be used to enhance the compressive strength, which raises the possibility of this waste material to be used for building and construction. Even at high level of crude oil contamination (10%), which showed a lower compressive strength by around 50% compared to uncontaminated, can be used for low-load bearing engineering application such as landfill layering and production of bricks. Based on 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 [36], respectively, whereas the Wastewater Technology Centre (WTC), Canada [37] 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 study investigated the effect of light crude oil contamination on the compressive strength of mortar. Based on the results, the following conclusions were drawn:

- Increasing the percentages of light crude oil contamination from 0.5% up to 10% increases the workability of the mortar 150 ±10mm, which indicates that the light crude oil works as a plasticing agent.
- The total porosity of all different of crude oil contamination (0%-10%) with advancement of hydration period decreased. This may due to the gradual filling of large pore by hydration products of cementitious material
- The pore size distribution influenced more the developed compressive strength than the total porosity. More specifically, the macroporosity (> 30 μm) has a direct correlation on the compressive strength than the micropores and mesopores.
- The strength properties of cement mortar with oil contaminated sand up to 10% are suitable for landfill layering and production of bricks results indicating their high potential and beneficial use in civil engineering and construction.

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