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An experimental investigation on applying the recycled aggregates obtained from oil contaminated concrete exposed to seawater as road unbound pavement materials

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HIGHLIGHTS

- Overall, in comparison with virgin sample, by increasing of contamination percentages, the SE values have no significant changes, but the values of soundness and abrasion ratio increase meaningfully.
- Oil contamination has no significant effect on maximum dry density, optimum moisture and aggregates strength variations.
- There are good correlations between water absorption-optimum moisture content, maximum dry density-CBR and Los Angles abrasion-soundness.
- Totally, CRA used in this research are appropriate for sub-base layer, but they are not suitable for base layer.

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ABSTRACT

By the population growth and the increasing need in new roads construction and also the maintenance services of the existing roads and with the attention to the reduction of natural materials, using the recycled aggregates (RA) from construction and demolition waste (CDW) is spreading around the world. One of the most important resources of RA is oil contaminated concrete of oil platforms and wharfs which are exposed to sea water. In this paper, first of all, the cubic samples of oil contaminated concrete with different percentages of contamination were built. The curing of the samples was done in the sea water (Indian Ocean-Chabahar coast/Iran). Then the samples were broken and crushed under experimental conditions. In the rest, the recycled oil contaminated aggregates were sieved and the possibility of the use of them as the granular aggregates of sub-base and base layers according to AASHTO and ASTM was investigated. The experimental results show that there is no considerable differences with the code recommendations.

1. Introduction

Recycled concrete aggregate is a kind of aggregate which is made by crushing and reclaiming the concrete which is already used in construction. Nowadays, due to the limitation of natural resources, researchers are interested in using recycling industry in all fields. A review on the done relevant existing articles show that we can use recycled aggregates in asphalt [1,2], concrete [3–5], sub-base and base layers and so on [6–11]. The Construction and demolition operations produce a vast quantity of constructional wastes. Table 1 shows the percentage of recycled materials out of construction and demolition wastes in different European countries [12].

Pavement is a multi-layer structure consisted of an asphalt or concrete course which is on the different layers like base, sub-base and subgrade. Normally, natural aggregates like gravel and broken stone are used in base and sub-base layers. During last two decades, some studies have been done to investigate the possibility of using recycled concrete aggregates in base and sub-base layers in order to provide a substitutable option for using construction and demolition wastes. The most frequent tests performed in such studies are particle gradation, compaction, water absorption, flakiness, Los Angles abrasion, soundness, Sand Equivalent (SE) and California Bearing Ratio (CBR).

Jimenez et al. [7] made a research to evaluate the behavior of two recycled aggregates from selected CDW in field conditions. One experimental unpaved rural road with two sections was built. They found that both recycled aggregates were of good quality and met all limits, except the soluble salt content, which was identified

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Table 1
Percentage of recycled material out of CDW in Europe [12].

Country	CDW*	Recycling (%)	Country	CDW*	Recycling (%)
Denmark	5.27	94	Malta	0.8	0
Estonia	1.51	92	Holland	23.9	98
Finland	5.21	26	Poland	38.19	28
France	85.65	45	Portuguese	11.42	5
Germany	72.40	86	Romania	21.71	0
Greece	11.04	5	Slovakia	5.38	0
Hungary	10.12	16	Slovenia	2.00	53
Ireland	2.54	80	Spain	31.34	14
Italy	46.31	0	Sweden	10.23	0
Latvia	2.32	46	England	99.10	75
Lithuania	3.45	60	EU-27	531.8	46
Luxemburg	0.67	46	*Million tones		

as a critical property, established by the Spanish Technical Specification for materials used in structural layers. In a similar study, Agrela et al. [13] build real sub-base and base layers of roads with the use of mixed recycled cement-treated aggregates (MCRA). They found out MCRA have a good mechanical performance in terms of adequate compressive strength, low deflections under impact load and appropriate roughness values. Rafaela Cardoso et al. [14] analyzed the effects of compaction on particle size distribution curves and density, as well as the consequences of particle crushing on the resilient modulus, CBR and permeability. Also they made an analysis on the influence of incorporating different RA types on the performance of unbound road pavement layers as compared with those built with NA by means of the International Roughness Index and deflection values. Their results indicate that the performance of most RA is comparable to that of NA and can be used in unbound pavement layers or in other applications requiring compaction. Hassan et al. [15] researched about using petroleum contaminated soil in highway construction. They concluded that there is a potential to use of up to 15% of petroleum contaminated sand in surface asphalt mixes, while higher percentages (up to 40%) can also be used for medium or light traffic surface or base course layers.

Oil contaminated concrete is also a kind of construction and demolition waste which can be obtained from the demolition of large concrete structures like oil platforms and wharfs which are exposed to oil leakage. Furthermore, Over recent decades, the amount of hydrocarbon contamination (oil spill, leaking of petroleum from underground storage tanks, oil pipe leakage, etc.) of the soil and environment has considerably grown and at the current time, it forms an important section of contaminated waste materials in the environment [16]. Iran, having the second resources of oil in the world and having a long coastal line in the south which is the place for a lot of oil tankers to berth; most of its wharfs and oil platforms which contain a lot of concrete, are exposed to oil and its derivatives pollution. Hence, in this paper, experimental studies for feasibility of the use of recycled oil contaminated concrete aggregates in different unbound layers of road are investigated as the primary and main goal and this matter forms the basis for this study as it is so important to apply this vast quantity of oil contaminated aggregates in road construction which can help to conserve natural resources for next generations. Also, the effect of oil contamination on compressive strength of concrete is investigated as secondary and sidelong goal.

2. Materials and methods

2.1. Materials and sample preparation

For simulating the conditions of oil contaminated concrete existing in the wharfs and the oil platforms, we proceeded to build concrete cubic samples with different percentages of oil contamination: 1%, 2%, 4% and 6% using one type of natural aggregates source of Chabahar port (located in the south-east of Iran, the entrance gate to Indian Ocean) according to a specified mix design (Fig. 1). Adding more than 6% of oil has no effect on the contamination of concrete, because the oil floats on the surface of concrete samples and doesn't take part in concrete combination as observed during the experiment (Fig. 2-b).

For each percentage of oil contamination, cubic samples with the dimensions of 15 * 15 * 15 cm^3 were built. Then, the following samples were transferred to the sea environment of Chabahar Gulf and were exposed to tidal condition (Fig. 1). One year later, the samples were carried back to the laboratory. At first, the compressive test was performed on the samples. However, it was not our main goal of this study. Then, the samples were crushed by a jaw crusher and then the contaminated recycled aggregates (CRA) were prepared for the main purpose of this study which is the investigation of the feasibility of the use of CRA in different layers of road. It is also considerable that while crushing the concrete samples, an extreme smell of oil was still sensed.

In order to simplify the introduction of samples containing 1%, 2%, 4%, 6% of oil contamination, the following symbols are employed: A(1%), B(2%), C(4%), D(6%).

2.2. Test methods

The following tests were done on the CRA according to AASHTO and ASTM in order to identify characterization properties (gradation, elongation, flakiness, fracture, sand equivalent, soundness, Los Angles abrasion, water absorption tests) and mechanical behavior (modified proctor compaction and CBR tests) of materials (Fig. 2). It is noticeable that each test has repeated for three times and the results are presented as average quantities.

2.2.1. Characterization properties tests

Table 2 shows the gradation requirements of base and sub-base layers based on ASTM D-1241 [17]. In this study, the particle size distribution of type I, gradation C for base and sub-base aggregates was selected as the target and based on it, some samples from the CRA were provided in order to do the other tests. The reason for using this type of gradation is related to the limitation of particles sizes in concrete making procedure and its more popularity in the road projects of Iran.

Afterward, elongation and flakiness tests were done in order to determine the weight percentage of defected aggregates according to ASTM D-4791 [18]. The lower percentages in these tests lead to more quality of aggregates, meaning that they have more strength against the traffic load. On the other hand, the more fractured sides of aggregates cause more friction between aggregates and increase the shear strength and bearing capacity of them. The percentages of fractured particles for coarse aggregates was determined according ASTM D-5821 [19]. In order to do this test, about 1500 gr of CRA remained on No. 4 sieve were selected. Then by visual inspection, the materials with fractured face were separated. The fractured particles in coarse aggregate is defined by the ratio of the weight of materials with fractured faces to the total weight of materials.

The next test on the CRA was sand equivalent (SE) which was performed on the aggregates passing No. 4 sieve based on ASTM D2419 [20]. In fact, this test is used to determine the ratio of sand volume to the total volume of soil (sand, clay and mud) and briefly shows how clean the sand is. Sand equivalent is an important factor in construction and earthworks. The reason is that the existence of much sand rather than fine aggregates in soil causes a decrease in optimum water percentage and accelerates the soil compaction to its maximum compaction rate in road pavement. Also in asphalt, the high percentage of fine aggregates causes more energy consumption and consequently leads to asphalt weakening under passing loads. This test is used to determine the quality of pavement aggregates and could be known as a supplementary for aggregates gradation test.

Furthermore, the soundness test was done on the CRA to investigate strength of them against weathering factors. The aggregates that break because of freezing-thawing conditions or moisture variation must not be used in road layers. Weather-