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Recycling of waste spent catalyst in road construction and masonry blocks

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HIGHLIGHTS

- Waste spent catalyst consists primarily of silicates and aluminates.
- Stabilization of waste spent catalyst will yield high compressive strength to qualify as a stabilized road subbase or base material.
- Blending raw spent catalyst with other virgin aggregates could be utilized in road base and subbase construction.
- Spent catalysts, used as a partial cement replacement or as a cementitious additive, could be utilized in masonry blocks construction.
- No negative environmental impact is anticipated from the use of waste spent catalyst in construction.

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ABSTRACT

Waste spent catalyst is generated in Oman as a result of the cracking process of petroleum oil in the Mina Al-Fahl and Sohar Refineries. The disposal of spent catalyst is of a major concern to oil refineries. Stabilized spent catalyst was evaluated for use in road construction as a whole replacement for crushed aggregates in the sub-base and base layers and as a partial replacement for Portland cement in masonry blocks manufacturing. Stabilization is necessary as the waste spent catalyst exists in a powder form and binders are needed to attain the necessary strength required to qualify its use in road construction. Raw spent catalyst was also blended with other virgin aggregates, as a sand or filler replacement, for use in road construction. Compaction, unconfined compressive strength and leaching tests were performed on the stabilized mixtures. For its use in masonry construction, blocks were tested for unconfined compressive strength at various curing periods. Results indicate that the spent catalyst has a promising potential for use in road construction and masonry blocks without causing any negative environmental impacts.

1. Introduction

Managing waste materials is one of the most contentious issues faced by many countries. Disposal of waste materials in the environment is more restricted now by many industrial countries. One such waste generated in Oman is spent catalyst, which is produced by the Sohar and Mina Al-Fahl Refineries. Spent catalyst was evaluated for reuse in road and building construction.

Spent fluid catalytic cracking (FCC) catalyst, derived from the cracking of petroleum in the oil-refinery industry, is a waste material consisting principally of active silica and alumina [1]. Several researchers [2–8] recommended several alternative methods to manage the spent catalyst, including reclamation of metals, rejuvenation and reuse, disposal in landfills and preparation of useful products using spent catalysts as raw materials to replace sands or cement. Spent catalyst has high specific surface area and high pozzolanic reaction [9]. Also, more than 80% of its components are silicates and aluminates. Hence, it can be used as a partial replacement for sand or cement in mortars without affecting the compressive strength [4,9]. The leachate of heavy metals (V, Ni and Mo) can be stabilized by mixing spent catalyst with marine clay and fired above 1100 °C [2,10] or by utilizing the spent catalyst in cement products [4]. Moreover, it is a valuable material for the cement industry since it contains high amounts of silicates and aluminates [3]. Many studies were performed on the use of spent catalysts in cement mortars as an additive material or as a partial replacement for cement or sand. No research work was found on the use of spent catalyst in road bases and subbases.

This study was initiated to evaluate the utilization of stabilized spent catalyst for use in bases, sub-bases and embankments. Ordinary Portland cement, cement kiln dust or a combination of the two materials were used. The final stabilized product could be potentially used as a base or sub-base material in roads, parking lots, embankments, etc. California Bearing Ratio (CBR) and compaction tests were performed on selected mixtures to meet Omani specifications for materials used in road bases and sub-bases. Moreover,

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Table 1
Physical properties of spent catalysts.

Property	ASTM standard	Mina Al-Fahl (MF) spent catalyst	Sohar (SR) spent catalyst
Physical state	–	Solid	Solid
Color	–	White to off-white	Gray
Shape	–	Spheres or granules	Crystalline powder
Odor	–	Acidic smell and reacts very vigorously in water	Odorless
Solubility	–	Insoluble in water, oil and solvents	Insoluble in water, oil and solvents
Liquid limit (%)	D4318	51.9	72.8
Bulk specific gravity	C128	2.790	2.600
Sand equivalent (%)	D2419	92.6	NA[a]
L.A. abrasion (%)	C131	72.4	NA
Absorption (%)	C128	31.2	NA

[a] Not available.

spent catalyst was evaluated as a partial cement replacement or as a cementitious additive (without replacing cement) in masonry hollow blocks. Some of these applications were subjected to leaching tests using the Toxicity Characteristic Leaching Procedure (TCLP).

Some numbering indices were used for materials' designations. [SC-SR-n] refers to a spent catalyst sample mixed from all drums obtained from the Sohar Refinery. [SC-MF-n] and [SC-MF-c] refer to samples mixed from all drums obtained from the Mina Al-Fahl Refinery. The "*n*" means that the catalyst was used "as-received" and the "*c*" means that the catalyst was crushed to a certain size.

2. Experimental procedures

All physical, chemical, compaction and compressive strength tests on raw and stabilized spent catalysts were conducted in accordance with established ASTM procedures and equipment as indicated in the following sections. Omani standards were used in the preparation and testing of the masonry blocks.

3. Materials' characterization

Physical properties were determined in accordance with ASTM standards and the results are shown in Table 1. The bulk specific gravities were 2.79 and 2.60 for spent catalysts from Mina Al-Fahl and Sohar Refineries, respectively. The surface areas of the Sohar and Mina Al-Fahl Refineries' spent catalysts were 900 and 3235 cm^2/g, respectively. The high surface area of the Mina Al-Fahl was obtained after crushing the granular particles to pass 0.075 mm sieve opening. However, in stabilization work the Mina Al-Fahl's spent catalyst was crushed to pass 2.36 mm and in CBR it was used "as-received" without crushing the particles. Crushing occurred only as a result of the compaction process in the molds. Because of its original powder form, the spent catalyst from Sohar absorbs a higher amount of water than the material from Mina Al-Fahl. The chemical properties of spent catalysts indicate that the dominant components are SiO_2 and Al_2O_3, which constitute more than 68% of the composition of spent catalyst from the Mina Al-Fahl Refinery and about 77% of the spent catalyst from the Sohar Refinery (see Table 2). The spent catalyst from the Mina Al-Fahl Refinery had more organics as confirmed by the high loss-on-ignition (LOI) value.

4. Stabilization of spent catalyst

4.1. Optimum moisture content (standard and modified proctor compaction)

Three different percentages of ordinary Portland cements at 3%, 5% and 7%, by weight of spent catalyst were initially added to the material from both refineries. Water was added as a percent of the total dry weight of the spent catalyst and the binder. In order to determine the optimum moisture content (OMC), at least five samples were prepared at different water contents. The OMC was determined using both standard and modified proctor compaction (ASTM D698 and ASTM D1557) with the aid of an automatic compactor. The moisture results were found after 24 h of drying at an oven temperature of $110 \pm 5\,^{\circ}C$. Table 3 indicates that the spent catalyst required high amounts of water to reach the OMC, and the catalyst from the Sohar Refinery absorbed more water than the catalyst from the Mina Al-Fahl Refinery, which could be attributed to the fine particle size (high surface area) and chemical composition of the former catalyst. Table 3 further indicates that as the cement content increased, the OMC decreased slightly. Modified proctor provides more energy to the compacted mix. Thus, the densities of the mixes were slightly higher than those obtained from a standard compaction test.

4.2. Unconfined compressive strength (UCS)

Twenty seven specimens were prepared at OMC for compressive strength testing (ASTM D2166) of the Sohar catalyst. Those specimens were tested after 7, 14 and 28 days of curing using a 100 kN compressive machine with a loading rate of 1 mm/min and the results are shown in Fig. 1. Three samples were prepared for each cement content at the optimum water contents determined in Section 3. Thus, compressive strength values obtained on stabilized spent catalyst represent the average of three samples. The results indicate that there is a direct relation between strength and

Table 2
Chemical properties of spent catalysts (%).

Composition	Mina Al-Fahl (MF) spent catalyst	Sohar (SR) spent catalyst	Ordinary Portland cement (OPC)	Cement kiln dust (CKD)
SiO_2	1.71	39.21	19.95	15.84
Al_2O_3	66.66	37.68	5.96	3.57
Fe_2O_3	0.07	0.66	6.00	2.76
CaO	0.08	0.05	60.85	63.76
MgO	0.02	0.26	1.95	1.93
Na_2O	8.29	0.43	1.75	0.33
K_2O	0.26	0.06	0.22	2.99
LOI	26.13	2.43	2.45	5.38

LOI, loss-on-ignition.