Construction and Building Materials 78 (2015) 281–288

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Encapsulation of petroleum sludge in building blocks

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HIGHLIGHTS

- Examines the encapsulation of petroleum sludge in block production.
- Evaluation of the physical and mechanical properties of blocks manufactured with petroleum sludge.
- Provides an alternative to petroleum sludge disposal.
- Confirm the environmental acceptability of petrovege block.

ARTICLE INFO

Article history:
Received 29 May 2014
Received in revised form 27 November 2014
Accepted 31 December 2014
Available online 17 January 2015

Keywords:
Petroleum sludge
Vegetable oil
Petrovege block
Unconfined compressive strength
PAH

ABSTRACT

Petroleum sludge is one of the major solid wastes generated in the petroleum industry; cost-effective treatment and proper disposal has become a problem worldwide. The use of it as a raw material in the production of building blocks was investigated in this paper to find an alternative to dumping this environmentally unfriendly material into land fill. The petroleum sludge and aggregates were characterized in terms of their composition and grain sizes respectively. The block samples were prepared by adding 8%, 9%, 10%, 11%, 12%, and 13% liquid content of the mixture of vegetable oil and petroleum sludge as a binder. The mixtures were compacted in a cylindrical mold of 50 mm × 100 mm sizes with 75 blows using Marshall compacting machine, then were cured through oxidation in an oven at 160 °C for 48, 72, 96 and 120 h. The physical and mechanical properties were evaluated and the high compressive strength recorded compare to conventional building blocks has made it more feasible and interesting in the construction industry.

1. Introduction

In the production and exploration of petroleum, wastes are generated which includes drilling fluid, petroleum waste water, petroleum effluent treatment plant sludge and bottom tank sludge. Up to five percent of all crude oil produced is not viable. Petroleum refinery with a production capacity of 105,000 barrels per day produces about 50 tons of oil sludge per year [1].

Sludge is a general term used to describe the residual deposits found at the bottom of tanks and other storage vessels. Sludge found in crude oil storage tanks is typically made up of hydrocarbons, asphaltenes, paraffin, water, and inorganic solids such as sand, iron sulfides and iron oxides. An analysis of crude oil sludge shows that greater than 90% of the sludge material is composed of the valuable paraffin, asphaltene, and hydrocarbon. Sludge forms when a crude oil's properties are changed due to changes in external conditions. Cooling below the cloud point, evaporation of light ends, mixing with incompatible materials, and the introduction of water to form emulsions, make up the most common causes for sludge formation [2].

According to Resources Conservation and Recovery Act (RCRA) sludge is one of the hazardous wastes [3]. The elemental composition of petroleum sludge are nitrogen, phosphorous, potassium, iron, calcium, magnesium, manganese copper, cadmium, chromium, lead, zinc, phosphate, nitrogen, calcium, magnesium, sodium, potassium, iron, manganese, lead and chromium [4].

Crude oil sludge is a recurrent problem leading to corrosive effect and reduction in oil storing capacity. For this to be removed it required high cost. The economic effect involves the cost of sludge removal and disposal, where the greater expense is the disposal fee of the environmentally-unfriendly material.

In recent years, a variety of methods of processing and disposing of petroleum sludge are used globally: thermal, mechanical, biological, and chemical. All these are not economically sustainable. In addition to the cost of removing, transporting, and land filling involved in cleaning up petroleum sludge, it also contains various

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http://dx.doi.org/10.1016/j.conbuildmat.2014.12.122
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toxic elements present in the hydrocarbon. These contaminants include petroleum hydrocarbons, such as aliphatic hydrocarbons and polycyclic aromatic hydrocarbons (PAHs); over 33% of total petroleum hydrocarbons (TPH) with 550 mg/kg of polycyclic aromatic hydrocarbons (PAH) are present in crude oil sludge [5], polychlorinated biphenyls (PCBs), and heavy metals, including barium, lead, zinc, mercury, chromium, arsenic, and nickel [6–8]. Removal of tank sludge is a significant item of tank maintenance for producers, refiners and transporters of petroleum materials. All tanks eventually accumulate sludge, but the worst problems occur in crude tanks at production locations. Beneficial reuse from small production sites requires that the sludge material be reused without treatment. The use of this waste as a construction material should prove very economical and environmentally sustainable.

In a research carried out to find some alternatives to bitublocks limitations, it was discovered that vegetable oil can be used as non-traditional binders and it can easily be mixed with recycled aggregates at ambient temperatures to produce a very workable, easily compactable product named vegeblock. The curing was done through full oxidation of the vegetable oil which then results in the stability of the block [9]. Based on the chemical composition of vegetable oils, the curing time has been established between 12 and 24 h at 120 °C and 160 °C [10]. The physio-mechanical properties of the blocks are within acceptable threshold compared to concrete blocks.

The oxidation of oil occurs when atmospheric oxygen attacks the weak areas of hydrocarbon molecules. Saturated hydrocarbons are carbon molecules that contain exclusively carbon–carbon bonds (C–C). Since no refinement process is completely 100% successful, the hydrocarbons will contain weak areas. These weak areas are typically carbon–carbon double bonds ($C{=}C$), or similarly reactive chemical species. Oxygen, in the presence of heat, is able to chemically alter the $C{=}C$ in the hydrocarbon, to initiate the formation of peroxides (RCOOH). The newly formed peroxides degrade through a free radical process to form hydroperoxides. The formation of hydro peroxides is highly unfavourable as these chemical species will, through a condensation polymerization process, form high molecular molecules. The presence of metal salts in the component acts as a catalyst to further increase the rate of this process. After a significant degree of oxi-polymerization has occurred the oil will have a substantially increased viscosity. The increase in viscosity is a direct reflection of the physical size of the polymers themselves which lead to the hardening process of the oil [11].

This study is to investigate encapsulation of petroleum sludge in building blocks using oxidized vegetable oil as binder and evaluate it suitability. It will focus on determining the general quality of building blocks made using petroleum sludge. The study will starts with the characterization of the properties of the petroleum sludge. This will be followed by the evaluation of the physical and mechanical properties and environmental analysis to characterize the potential for release of hazardous compounds from the finished product.

2. Materials and methods

2.1. Petroleum sludge

The petroleum sludge used in this study was taken from PETRONAS refinery at Melaka, Malaysia. The petroleum sludge was dried in an oven for 48 h at a temperature of 110 °C and soxhlet extraction was done on it based on EPA method 3440 [12]. Soxhlet extraction was done using dichloromethane (DCM) and acetone (1 + 1). The soxhlet apparatus consisted of a 250 ml round-bottomed flask, a condenser and extractor tube, seated in a temperature-controlled heating mantle was heated for 24 h. One third of the extract was concentrated to 10 ml on a rotary evaporator and evaporated under a gentle flow of nitrogen gas. Determination of possible presence of PAHs was done using gas chromatography/mass spectrometry (GC/MS) US EPA Method 8100 (USEPA [13]). The condition of the GC/MS is shown in Table 1.

2.2. Vegetable oil

The vegetable oil used was a pure vegetable oil of Double fractionated supergrade 100% pure palm olein, generally available in Malaysia market with fatty acid composition of 44.3% saturated, 12.1% polyunsaturated, and 43.6% monounsaturated.

2.3. Sand Aggregates

The sand used were of two types, the size distribution of the sands were done using the dry sieving and hydrometer in accordance with ASTM C 136-96a [14] and the specific gravity of the sands were also determined using helium ultrapycnometer and large pycnometer method in accordance with ASTM C127-88 & C128-88 [15].

The chemical composition of the sand samples were examined using X-ray fluorescence (XRF) spectroscopy. This is a non-destructive analytical method in which X-ray tube was used to irradiate the sample with a primary beam of X-rays.

2.4. Specimen preparation

600 g of mixture of two sands (river and crushed) 50% of each was used. Weighed quantities of two types of sand were mixed together. The wet binder was then prepared by manually mixing the petroleum sludge and the vegetable oil (1:1) until a homogeneous mixture is obtained, the binder content was 8%, 9%, 10%, 11%, 12% and 13% by weight and was then added to the sand. After thorough mixing, the freshly prepare mixes were placed in cylindrical molds (50 mm × 100 mm) and compacted using Marshall compacting machine with 75 blows and left to cure through oxidation in an oven for 48 h, 72 h, 96 h and 120 h at a temperature of 160 ± 2 °C and 200 ± 2 °C. The mixing ratio is shown in Table 2.

3. Testing procedure

A set of physical and chemical tests were conducted on the petrovege block samples, tests were done in triplicate after curing time in accordance with adopted standards and guides from

Table 2
Specimen mixing ratio.

Material	Wt. (g)	%
Sand 1	300	50
Sand 2	300	50
Binder	48–78	8–13

Table 1
Gas chromatography/mass spectrometry conditions.

Technique	GC/MS
Column	Capillary column; 30. Length, 0.25 mm diameter
Injection volume	1 µl
Oven	5 ramp: 70 °C at 10 °C/min a 3 min hold, then to 326 °C at 4 °C/min, then to 350 °C at 10 °C/min with a 10 min final
Inlet Temperature	275 °C
Carrier gas	Helium, 1.2 ml/min
Detector temperature	280 °C
MS operating (data acquisition mode)	SIM Mode; EI ionization with a 2000 eV, (The multiplier voltage on the mass spectrometer was held at 2000 eV)
Transfer line	300 °C