Construction and Building Materials 159 (2018) 277–285

Contents lists available at ScienceDirect

Construction and Building Materials

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

Engineering properties of Controlled Low-Strength Materials containing Treated Oil Sand Waste

A. Mneina [a], A.M. Soliman [b], A. Ahmed [a,c,*], M.H. El Naggar [a]

[a] Department of Civil and Environmental Engineering, The University of Western Ontario, London, Ontario N6A 5B9, Canada
[b] Department of Building, Civil and Environmental Engineering, Concordia University, Montreal, Quebec H3G 1M8, Canada
[c] Civil Engineering Department, Beni-Suef University, Beni-Suef, Egypt

HIGHLIGHTS

- Treated oil sand waste (TOSW) was successfully incorporated in CLSM mixtures.
- The effect of TOSW on the physical and mechanical properties was investigated.
- Environmental evaluation showed that TOSW can be safely used in CLSM.

ARTICLE INFO

Article history:
Received 17 May 2017
Received in revised form 17 October 2017
Accepted 21 October 2017

Keywords:
Controlled low strength materials
Oil sand waste
Drill cutting waste
Leaching
Shrinkage

ABSTRACT

Controlled Low-Strength Materials (CLSM) is a self compacted self-leveling cementitious material with compressive strength of 8.3 MPa or less. It is used as an alternative of soil backfill materials in geotechnical and infrastructure applications. This study investigates the effects of incorporating Treated Oil Sand Wastes (TOSW) as a partial replacement of sand or fly ash on fresh and hardened properties of CLSM. In addition, the environmental impact of the proposed new mixtures was evaluated. The results show that CLSM mixtures incorporating TOSW had satisfied the limits and requirements of ACI committee 229 for CLSM with no environmental hazards. The incorporation of TOSW has increased the flowability of all mixtures and consequently reduced the water demand to reach the required flowability which consequently increased the compressive strength of mixtures containing TOSW and flyash. Replacing flyash with TOSW on the other hand, reduced the strength of CLSM slightly, but the strength remains within CLSM acceptable range of strength. In addition, this produced a more re-excavatable mixture, adequate for applications that may require future re-excavation. This successful incorporation of TOSW in CLSM mixture will provide a safe recycling method for oil sand wastes while reducing the environmental footprint of both construction and oil sand industry.

1. Introduction

With the increasing demand for energy, new technologies are developed for oil extraction from oil sands. Consequently, oil sand industry became an important source for hydrocarbons with large reserves in western Canada [1]. This has led to more challenges regarding waste management due to the large amount of waste in the form of oil sand tailings that need to be landfilled. Many technologies have been developed to treat these tailings and reduce the amount of waste directed to landfill. One of the recent technologies is Thermo-Mechanical Cuttings Cleaner (TCC), which separates water and oil from the oil sand solid waste [2,3]. The remaining part of the tailing is fine particles, mainly quartz crystals, which is referred herein as Treated Oil Sand Waste (TOSW) [4,5]. The particle size distribution of TOSW is shown in Fig. 1.

The TCC technology removes most of hydrocarbons from the waste leaving less than 1000 mg/kg of hydrocarbons in TOSW [6].

The effect of using petroleum-contaminated drilling waste as sub-base material for road construction was investigated by Tuncan et al. (2000) [7]. The petroleum waste used in this study was stabilized by mixing it with pozzolanic fly ash, lime, and cement. Physical, mechanical, and chemical properties of the new mixtures were studied and found to have better properties compared to the commonly used sub-base materials. The potential uses of petroleum contaminated soil (PCS) in highway construction were also investigated by Hassan et al. (2004) [8]. Their investigation

* Corresponding author at: Department of Civil and Environmental Engineering, The University of Western Ontario, London, Ontario N6A 5B9, Canada.
E-mail addresses: aahme243@uwo.ca, aly_76@hotmail.com (A. Ahmed).

https://doi.org/10.1016/j.conbuildmat.2017.10.093
0950-0618/

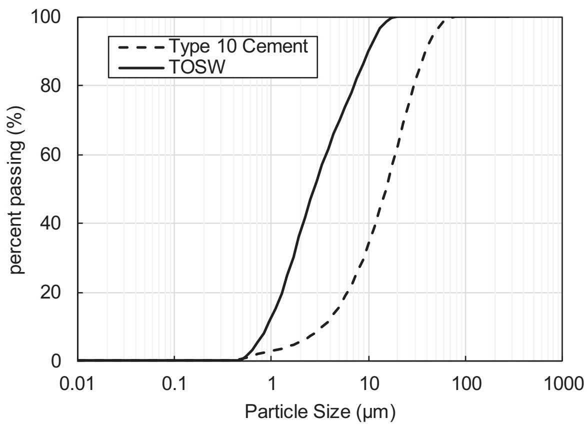

Fig. 1. Particle size distribution of type10 cement and TOSW.

included the stabilization of the tested soil with cement and crushed stone aggregates. The new mixtures were used as replacement for fine aggregates in asphalt concrete mixtures. A toxicity characteristic leaching procedure (TCLP) was conducted on the tested soil specimens and found to be non-hazardous. The unconfined compressive strength for cement-stabilized contaminated soil at a percentage of 5% remained relatively constant with increasing the cement content. An adverse effect on the cement hydration caused by the addition of waste was also noticed. However, the tested waste was still deemed a good potential for use in road construction. Moreover, Hassan et al. (2008) [9] investigated the permeability and leaching of asphalt concrete mixtures containing oil-contaminated soils (OCS) as a partial replacement of fine aggregates with percentages up to 40% by weight [9]. A reduction in the tested asphalt permeability was observed with increasing the OCS percentage. This reduction was significant for OCS up to 30%.

The effect of using oil drill cuttings in road construction was also investigated (Misra et al. 2011) [10]. Their results showed that drill cuttings waste can provide a stable and strong sub-grade for roads with minimal amount of heavy/toxic metals, which makes it suitable to be safely used in road construction. The potential use of mine tailings wastes as a base material for unpaved roads had been studied (Mahmood and Mulligan 2010) [11]. Physical characteristics and unconfined compressive tests were performed on different types of tailings wastes brought from several mines in eastern Canada. The results revealed that all tested samples have exceeded the minimum strength requirements, hence, this type of waste could be used as a base material for unpaved temporary access roads.

Controlled low-strength material (CLSM) is a flowable self-levelling cementitious material; it is widely used as a replacement for soil-cement materials in many geotechnical applications such as structural backfill, pipeline beddings, void fill, pavement bases and bridge approaches. Because of its low strength requirements, CLSM can be a perfect host for many waste and by-products given that these materials have been proven environmentally safe [12,13]. Many studies have evaluated the effect of incorporating different by-products, such as spent foundry sand, cement kiln dust, wood ash, scrap tire rubber and coal combustion by-products on the properties of CLSM [14].

The main properties for CLSM performance are flowability, density, and compressive strength. However, other properties like shrinkage, bleeding and subsidence were also evaluated. The upper limit of compressive strength of CLSM can be up to 8 Mpa, however, maintaining a low strength is essential for projects where later excavation is required. CLSM with a compressive strength of 0.7 and lower can be easily excavated manually if there is no high content of coarse aggregate in the mixture [15].

The removability modulus (RE) can be used to assess the excavatability of a CLSM mixture based on its strength and dry density (Eq. (1)).

$$RE = \frac{W^{1.5} \times 0.619 \times C^{0.5}}{10^6} \quad (1)$$

where W is the dry density of the mixture in (kg/m^3), C is the compressive strength at 28 days in (kPa). The CLSM mixture is considered easily removable if RE is less than 1 [15].

The main objective of this paper is to investigate the potential of incorporating TOSW in CSLM as a fine filler material in order to produce green CLSM. This will be an important contribution to the efforts of reducing the footprint of oil sands industry by recycling TOSW and reducing the amount of natural sand used in CLSM. Using TOSW as a fine filler will alter the properties of CLSM either chemically or physically; therefore, it is important to evaluate the properties of the new CLSM to maintain the performance within the requirements of ACI committee 229 for deferent geotechnical applications.

2. Experimental program

2.1. Materials

Type 10 Ordinary Portland Cement (OPC) with Blaine fineness of 360 m^2/kg and specific gravity of 3.15 and Class F fly ash according to ASTM C618 [16] were used as binding material in CLSM mixtures. It contained 61% Tricalcium Silicate (C_3S), 11% Dicalcium Silicate (C_2S), 9% Tricalcium Aluminate (C_3A), 7% Tetracalcium Aluminoferrite (C_4AF), 0.82% equivalent alkalis and 5% limestone. Treated Oil Sand Waste (TOSW) was used as a silicate base fine filler material with a Blaine fineness of 1440 m^2/kg and specific gravity of 2.23. The chemical composition and the physical properties of the cement, fly ash and TOSW are shown in Table 1.

Three groups of mixtures were prepared and tested in the current study: Group 1 included control mixtures prepared based on proportion guidelines reported by ACI committee 229. All mixtures were mixed with natural river bed sand with a specific gravity of 2.65. Group 2 included six mixtures where TOSW was added as a partial replacement of sand by volume at rates of 5%, 10%, and 15%. Group 3 was comprised of nine mixtures prepared with TOSW as a replacement of 100% of the fly ash along with partial replacement of sand by volume at rates 5%, 10% and 15%. Mixture proportions are shown in Table 2.

Table 1
Chemical composition and physical properties of cementitious materials.

Chemical Composition	OPC	TOSW	Fly ash
SiO_2	21.60	61.24	43.39
Al_2O_3	6.00	8.73	22.08
Fe_2O_3	3.10	3.00	7.74
CaO	61.41	5.55	15.63
MgO	3.40	0.92	–
K_2O	0.83	1.60	–
Na_2O	0.20	0.85	1.01
P_2O_5	0.11	0.15	–
SO_3	1.76	3.00	1.72
TiO_2	–	0.46	–
Physical properties			
Surface area (m^2/kg)	360	1440	280
Specific gravity	3.15	2.23	2.5