Journal of Hazardous Materials 286 (2015) 503–508

Contents lists available at ScienceDirect

Journal of Hazardous Materials

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

Time-dependent performance of soil mix technology stabilized/solidified contaminated site soils

Fei Wang[a,*], Hailing Wang[b], Abir Al-Tabbaa[a]

[a] *Department of Engineering, University of Cambridge, Trumpington Street, Cambridge CB2 1PZ, UK*
[b] *College of Environment, Nanjing Tech University, Nanjing 210009, China*

HIGHLIGHTS

- The physical and chemical performances of most mixes were improved with time.
- Modified clays are efficient in immobilizing Ni.
- A small amount of organo clay is able to improve the strength of samples.
- M (MgO) and MG (MgO + GGBS) are efficient in immobilizing heavy metals.
- MgO based blends have showing outstanding effect on treating organic pollutants.

ARTICLE INFO

Article history:
Received 6 November 2014
Received in revised form 2 January 2015
Accepted 4 January 2015
Available online 6 January 2015

Keywords:
Field trials
Modified clay
Novel binders
Soil stabilization

ABSTRACT

This paper presents the strength and leaching performance of stabilized/solidified organic and inorganic contaminated site soil as a function of time and the effectiveness of modified clays applied in this project. Field trials of deep soil mixing application of stabilization/solidification (S/S) were performed at a site in Castleford in 2011. A number of binders and addictives were applied in this project including Portland cement (PC), ground granulated blastfurnace slag (GGBS), pulverised fuel ash (PFA), MgO and modified clays. Field trial samples were subjected to unconfined compressive strength (UCS), BS CN 12457 batch leaching test and the extraction of total organics at 28 days and 1.5 years after treatment. The results of UCS test show that the average strength values of mixes increased from 0–3250 kPa at 28 days to 250–4250 kPa at 1.5 years curing time. The BS EN 12457 leachate concentrations of all metals were well below their drinking water standard, except Ni in some mixes exceed its drinking water standard at 0.02 mg/l, suggesting that due to varied nature of binders, not all of them have the same efficiency in treating contaminated soil. The average leachate concentrations of total organics were in the range of 20–160 mg/l at 28 days after treatment and reduced to 18–140 mg/l at 1.5 years. In addition, organo clay (OC)/inorgano–organo clay (IOC) slurries used in this field trial were found to have a negative effect on the strength development, but were very effective in immobilizing heavy metals. The study also illustrates that the surfactants used to modify bentonite in this field trail were not suitable for the major organic pollutants exist in the site soil in this project.

1. Introduction

Effectively treating organic and inorganic contaminated soil has been found to be a big challenge due to their nature and transport mechanisms in a soil environment [1]. Compared with existing treatment options, such as soil washing, biological methods, and disposal to landfill [2], soil mixing technology is a cost-effective, versatile, and low risk method for the implementation of a range of in-situ remediation treatments [3,4]. Stabilization/solidification (S/S) as an application of soil mix technology has specific advantages relating to cost and environmentally friendliness [5]. The most popular materials in S/S are conventional binders such as Portland cement (PC) and lime [6], and some industrial by-products such as pulverised fuel ash (PFA) and ground granulated blastfurnace slag (GGBS) [7]. Recently, attention has been put on novel binders such as MgO, and modified clays such as organo clay (OC), Inorgano–organo clay (IOC) [7–9]. OC is reported as being able to adsorb more organic pollutants compared to raw clays [8,10]. The modifications of bentonite to produce OC include oxide

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* Corresponding author. Tel.: +44 7909 488269.
E-mail addresses: fw281@cam.ac.uk (F. Wang), wanghailing@njtech.edu.cn (H. Wang), aa22@cam.ac.uk (A. Al-Tabbaa).

http://dx.doi.org/10.1016/j.jhazmat.2015.01.007
0304-3894/

pillaring which modifies the layered crystalline inorganic compound to produce a material with micro and meso porosity, and organic surfactant modification through cation exchange with alkylammonium ions. The combination of these two methods forms IOC minerals, which can treat inorganics and organics simultaneously [11,12]. However, studies of these binders, modified bentonites, have been mainly restricted to laboratory investigations [13]. Testing the performance of these novel binders and addictives is required to expand the boundaries of the soil mixing technology. In addition, whether a treatment technique is successful or not depends on its performance during its end-use expected lifetime [13]. Wang et al. [4,25] studied the leaching performance of S/S treated samples at 0.2, 2.4, 5 and 17 years, and found that lower concentration of heavy metals leached at 17 years after treatment than this at 5 years, and found that the hydration process of treated samples did not completed at 5 years but fully completed at 17 years. Roy and Cartledge [37] studied the long term behavior of PC treated sludge waste and found that the appearance of the principal Cu-bearing phase ($CuO{\cdot}3H_2O$) was both time and concentration dependent. Subtle changes of Cu in the microchemistry occurred over time. Hence, an assessment of the time-dependent performance of novel binders and modified clays in treating organic and inorganically polluted site soil are necessary in validating the effectiveness of this remediation process.

The objectives of this trial were to: (1) compare the strength and leaching performance of S/S treated site soil samples at 28 days and 1.5 years, (2) enable a better understanding of binder-contaminant interaction mechanisms, and (3) assess the application of OC/IOC in treating organic and inorganic contaminated soil.

2. Site, material and methods

Project SMiRT (Soil Mix Remediation Technology), was the largest contaminated land remediation project funded by the Technology Strategy Board. It involved collaboration with 16 industrial partners, over a four-year period which started in October 2007 and finished in September 2011 [3]. Soil treatment by S/S took place at a site in Castleford, Yorkshire in May 2011, as shown in Fig. 1. A triple auger system was applied which mixed contaminated soil with a range of binder blends consisting of PC, PFA, GGBS, MgO, Zeolite, OC and IOCs.

Table 1
Soil contaminant concentrations [35].

Metals or organic contaminants	Concentration range (mg/kg)
Pb	95–175
Zn	150–220
As	130–140
Cr	700–1150
Cu	1075–1600
Ni	1170–2200
VOCs: BTEX	≤7
SVOCs: anilines, chloroanilines, nitrobenzenes, dinitrotoluene	≤1400
TPHs	≤8000

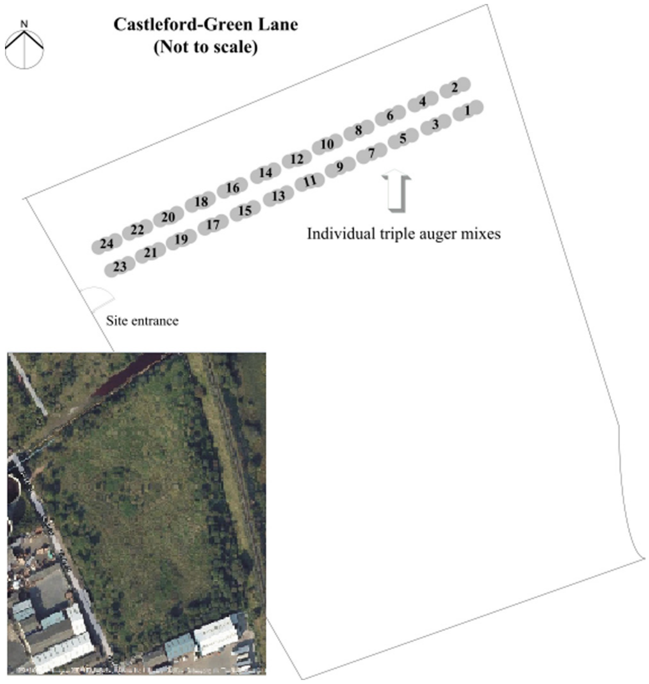

Fig. 1. Plan of field trials treatment.

The geology at the site consists of top soil (0.1–0.35 m), made ground (0.35–4.5 m) (consisting of black sand and/or silt containing fragments of plastic, concrete and wood), silts and clays (4–6 m) and sand and gravel (6–8 m). Natural drift deposits were found in the silts and clays zone as well as the sand and gravel zone. The groundwater level varies between 3.2 and 3.9 m below ground level [14]. The water content of the soil is ~25%, the liquid limit is ~30% and the plastic limit is ~24%. Due to historic disposal of waste materials, significant contamination was anticipated. Soil and groundwater samples were forwarded to Alcontrol Geochem in Chester (a URS approved laboratory) for chemical analysis at regular intervals during the fieldwork period [14]. Contaminants and their concentrations in the soil are listed in Table 1.

Although a total of 24 soil-grout compositions were applied at the site, only 14 of these mixes were selected for a detailed study in this paper. The layout of the 24 installations can be found in Fig. 1. PC (P), PFA (F), GGBS (G), MgO (M), OC and IOCs were materials used in the mixes, where each mixes were named after these materials' abbreviations. The 14 mixes were divided into 4 groups based on binder compositions for purpose of comparison, as shown in Table 2. The materials (excluding IOCs) used in this project were bought from material supply companies. The PC used in this project is CEM I. Granular OC used in the study was obtained from Amcol Minerals Europe Ltd. (with di(hydrogenated tallow) dimethyl ammonium chloride and di(hydrogenated tallow) methyl ammonium chloride surfactants on sodium bentonite clay) and IOCs were prepared in the laboratory with their compositions detailed in Table 3. The binder ratios used in this project were based on a preliminary laboratory study. In Table 2, PG, PF, PFM and P in group 1 are PC based, the slurry content of which is 15%; P-OC, P-2IOC1, P-IOC1, P-IOC3 in group 2 are 15% PC with different types of modified clays; PG-IOC3, PF-IOC3, PFM-IOC3, MG-IOC3 in group 3 are IOC3 based mixes, with 15% binders + 7.5% extra IOC3 slurry; M, MG in group 4 are MgO based binders.

Sampling took place at 28 days after treatment, 1 m length cores were collected in sealed plastic tubes to 4 m depth. The diameter of the cores decreased with depth from 0 to1 m: 90 mm, 1 to 2 m: 80 mm, 2 to 3 m: 70 mm and 3 to 4 m: 55 mm. After testing at 28 days, samples were cured in their original sealed plastic tubes in a temperature controlled laboratory at ~20 °C. The relative humidity of the lab is ~50%.

A saw cutter was used to trim cores into sections each with a length equal to twice the diameter of the core [15–17]. The ends of the sections were made flat to within ± 0.05 mm (see Fig. 2). The samples were tested at 28 days and again at 1.5 years. A core length and trimmed section are illustrated in Fig. 2. The samples were subject to UCS testing in triplicate based on ASTM D4219-08 test method using a Uniframe 70-T0108/E loading frame. The