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Three-year performance of in-situ mass stabilised contaminated site soils using MgO-bearing binders

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HIGHLIGHTS

- No apparent degradation of the mass stabilised materials after 3 years' exposure to the field conditions was found.
- The overall range of strength and leachability results at different depth was varied throughout.
- MgO-GGBS blends provided better performances compared to PC and MgO-only mixes in mass stabilised soils.

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ABSTRACT

This paper provides physical and chemical performances of mass stabilised organic and inorganic contaminated site soils using a new group of MgO-bearing binders over 3 years and evaluated the time-dependent performance during the 3 years. This study took place at a contaminated site in Castleford, UK in 2011, where MgO, ground granulated blastfurnace slag (GGBS) and Portland cement (PC) were mixed with the contaminated soils in a dry form using the ALLU mass mixing equipment. Soil cores were retrieved 40-day, 1-year and 3-year after the treatment. The core quality, strength, and the leaching properties were determined via physical observation, unconfined compressive strength (UCS) and batch leaching tests. After 3-year treatment, the UCS values of ALLU mixes were in the range of 50–250 kPa; the leachate concentrations of Cd, Pb, Cu and Zn (except Ni) in all mixes were lower than their drinking water standards; and the leachability of total organics was in the range of 10–105 mg/L. No apparent degradation of the mass stabilised materials after 3 years' exposure to the field conditions was found. MgO-GGBS blends were found able to provide higher strength and less leachability of contaminants compared to PC and MgO-only mixes in mass stabilised soils.

1. Introduction

Several techniques were applied to treat contaminated site soils over the past few decades, as contaminants can bring great risk to humans and animals [1,2]. Among these techniques cement-based soil mix technologies have been widely employed and investigated by a large number of studies [3–7]. Mass stabilisation as one of these soil mix technologies is effective and environmentally friendly for combining contaminated soil remediation and ground improvement treatments on the same site. It has been implemented for a few brownfields in the Nordic countries during the past few decades [8].

Portland cement (PC) is the most popular material in soil mix technologies. However, the production of PC is known to be highly energy consuming and releases ~5–10% CO_2 during its production process [9]. Under the drive of sustainability, by-products and novel binders such as ground granulated blastfurnace slag (GGBS) and MgO are drawing people's attention recently [9,10]. It was argued that MgO-based binders have advantages over CaO-based binders and provides additional unique benefits due to their adjustable properties and improved pH buffering capacity [10–12]. The immobilisation mechanism of MgO is mainly through precipitating the hydroxides and encapsulating contaminants into its hydration products (e.g. brucite). The main advantages of using MgO include: 1) the hydration of magnesia gives an equilibrium pH of ~10.5, and hence has a better precipitating action compared with PC/lime as the solubility of many heavy metals is lowest at

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that pH range [13,14]; and 2) brucite is able to accommodate a wide variety of heavy metals and organics by hydrogen bonding or through ion exchange [15,16]. In addition, the use of reactive MgO with GGBS for soil stabilisation has been reported as being able to offer a range of mechanical and chemical advantages over PC or lime-slag blends [1,9,10,17–19]. This is because the hydration products of MgO-GGBS mixes are calcium silicate hydrate (CSH)/magnesium silicate hydrates (MSH) and hydrotalcite-like (Ht) phases. The higher MgO/CaO ratio in these mixes increases the homogeneity of CSH gel structure, leads to a decreased Ca/Si ratio of CSH gel and the increased amount of voluminous Ht phases, which can fill the pores in the matrix more effectively [19,20]. However, limited studies about the effectiveness of mass stabilisation in treating organic and inorganic contaminated soils can be found, with even less field trials studies using MgO-bearing binders, hence assessment of site soils in real projects is essential for the validation of the efficiency of this type of binders in mass stabilisation system.

Apart from the type of binders, time is a significant factor that determines the remediation efficiency of contaminated lands. In the studies of Kogbara et al. [21] and Perera [22], it was found that with the aid of carbonation, the hydration process of PC-bearing binders were accelerated, hence the unconfined compressive strength (UCS) values of all mixes were improved with time at various extents. In most short-term cases (<10years) of stabilisation/solidification (S/S), due to the in-progress hydration, the release of contaminants is more likely to decrease with time [23]. However, Wang et al., [24] studied the leaching performance of S/S treated site soils at 0.2, 2.4, 5 and 17 years. It was reported that slightly higher concentrations of heavy metals were leached at 5 years after treatment compared to these at 0.2 and 17 years using a toxicity characteristic leaching procedure (TCLP) leaching test, and the hydration process of treated samples did not complete at 5 years but fully completed at 17 years. The leachate pH and the further carbonation are the cause of this fact. To date, very limited attention was given to real-life S/S materials, with even less to mass stabilised soils [22,25,26]. Although ground improvement (GI) treatment has been widely applied in the world, the application of MgO-bearing binders in mass stabilisation is a recent development, with very limited studies in the brownfield. For these reasons, it is necessary to understand the time-related performance of mass stabilised contaminated soils using MgO-bearing binders.

The objectives of this trial were to: (1) investigate the 3-year performance of mass stabilised contaminated soil samples at different depths, (2) compare the strength and leaching performance of the soil samples 40-day, 1-year and 3-year after the treatment, and (3) compare MgO-bearing binders and PC in mass stabilised contaminated soils.

2. Site, material and methods

The contaminated site characterisation can be referred to [1,27,28]. Individual GI ALLU mixes were installed in 2011 to form 31 square pits, with a plan area of 1.96 m^2, and 3–4 m in depth. Soils were pre-wetted, and then a total of 31 different combinations of binders were added in a dry form to the made ground soils. The soil strata consisted of made ground (~5% clay and silt, and ~95% sand) and the groundwater level was reported to vary between 3.2 and 3.9 m below ground level. The water content of the made ground soils was ~25%, while the liquid limit was ~30% and the plastic limit was ~24%. The main contaminants in the made ground tested in 2010 are Pb (38 mg/kg), Zn (99 mg/kg), As (128 mg/kg), Cr (495 mg/kg), Cu (823 mg/kg), Ni (806 mg/kg) and total organics (3605 mg/kg) [9]. The detailed contents of heavy metals and organic contaminants in the original soils at different depths can be seen in Fig. S1 (See in the online version at DOI: 10.1016/j.jhazmat.2016.07.018).

Table 1
Soil-binder constituents in percentage weight (wt%).

Mix denotation	Soil	Binder Contents		
		MgO	GGBS	PC
C5	95	–	–	5
M10	90	10	–	–
M5	95	5	–	–
M2.5	97.5	2.5	–	–
MG10(1:4)	90	2	8	–
MG5(1:4)	95	1	4	–
MG2.5(1:4)	97.5	0.5	2	–
MG10(1:9)	90	1	9	–
MG5(1:9)	95	0.5	4.5	–
MG2.5(1:9)	97.5	0.25	2.25	–

Table 2
Compositions of the binders used in the SMiRT project work (wt%) [33].

Main elements	CEMI	GGBS	MgO
SiO2	19.6	36.5	0.9
CaO	64.2	39.5	1.9
Al2O3	5.3	12.5	0.1
Fe2O3	3.5	0.5	0.8
MgO	1.0	8.5	93.5
SO3	–	–	–
K2O	–	0.4	–
Na2O	0.2	0.2	–
TiO2	–	0.5	–
Cl	0.04	–	–
LOI	3.1	–	2.78
Free CaO	2.1	–	–

Although 31 GI mixes in ALLU mass treatments were applied in the SMiRT project, only these treated by PC (C), MgO (M) and MgO-GGBS (MG) were selected for a detailed study in this paper. The compositions, by weight percentage, of those soil-binder mixes are presented in Table 1. The compositions of the binders used are shown in Table 2. The cores of decreasing diameters of 85, 75, 65 and 55 mm, were obtained and tested at around 1 month after treatment, they were then stored in their plastic cover until reopened 1 year after the treatment as part of this study for further testing. Those containing MgO, together with CEM I for comparison purpose, were sampled again after 3-year treatment from the site for detailed study. The core samples were sealed in Ø0.1 × 1.5 m plastic tubes and sent to the laboratory for testing.

Detailed testing procedure can be found in [1,27]. After 3-year treatment, the undrained shear strength on the soil cores was determined by a handheld shear vane tester and converted to the unconfined compressive strength by a factor of 2 (ASTM D2166). The crushed samples were then subjected to batch leaching according to BS EN 12457-2 (2002). The liquid to solid ratio (L/S) used was 10:1, adding 500 mL of carbonated deionised water in a bottle (pH = 5.4) containing 50 g of core sample. After 24 ± 3 *h* of agitation on a bottle roller, ~10 mL of the leachate solutions was filtered through a 0.45 μm filter and the pH of which was measured. Finally, a Perkin Elmer inductive couple plasma optical emission spectrometer (ICP-OES) was used to measure the leachate concentrations of heavy metals. The remaining extraction fluid from the batch leaching test was abstracted into a 1000 mL plug-contained conical flask for organic extraction, where 5 mL of 12 mol/L hydrochloric acid was added to speed up the extraction reaction and also acted as a pH buffer. Then, 90 mL of dichloromethane (DCM), serving as the solvent, was divided into 3 equal parts and each was added separately to the flask. After the extraction process, the entire extracted sample was then poured into a container, whose weight was pre-recorded, for DCM evaporation in a fume cupboard. The