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Experimental study on anti-seepage grout made of leachate contaminated clay in landfill☆

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A B S T R A C T

Leachate-contaminated clay was used as the base material, where cement and the self-developed clay curing agent were added to form an anti-seepage grout that can repair the leachate-contaminated clay in landfills, exhibit low permeability, and retard pollutants in the leachate. The effect of grout formula on the concentration of leaching pollutants, concretion rate, compressive strength, and permeability coefficient of concretion bodies was studied through a series of laboratory experiments. The efficiency of concretion bodies in retarding the leachate pollutants was investigated through a permeability test. The results indicated that the pollutants in the leachate-contaminated clay were controlled effectively. At 20% cement, 2% clay curing agent, and 1:1 water–soil ratio, the permeability coefficient of the concretion bodies after 7 days is ~10^{-7} cm/s, with >1 concretion rate and >1.2 MPa unconfined compressive strength. In addition, the concretion bodies reached >85% retardation rate for COD in the leachate and >99.8% for NH_3-N (including heavy metals such as Pb and Cd, among others). The retardation rate of the concretion bodies for the heavy metals is proportional to the ionic radius. As the cement content increased (clay curing agent = 10% cement), the concretion rate and permeability of the concretion bodies decreased, whereas its compressive strength increased.

1. Introduction

Municipal solid wastes (MSW) produce leachate during the landfill process because of various effects, such as rainfall eluviation, surface runoff, underground water infiltration, and degradation of microorganisms in the garbage, among others (Bou-Zeid and Ei-Fadel, 2004). Landfill leachate contains high concentrations of complex pollutants, which severely pollute the surrounding water, soil, and others once they leak into the environment (Sang et al., 2006; Ward et al., 2005). Currently, China has many unauthorized landfills, some of which exhibit different leakage degrees (Zhang et al., 2008). Therefore, pollution control and landfill repair have become a significant environmental problem that requires an urgent solution. Establishing an impermeability system is the most direct and effective measure that can prevent and control the pollution produced by leachate, and aims to control the leachate and its harmful pollutants within a certain range (Zhang et al., 1999). Therefore, a good impermeability system should have low permeability and high effectiveness in retarding leachate pollutants (Kugler et al., 2002). The vertical impermeable layer has been widely applied and constructed around landfills through grouting and other technologies, and is known for its good impermeability effect, lower cost, and easy restoration, among others (Łuczak-Wilamowska, 2002).

Generally, the impermeable layer of a landfill is made of soil-bentonite, cement-bentonite, prefabricated concrete, and other materials (Jones and Dixon, 2005; Xu and Yang, 2006). Stove ash or coal ash is added to these materials to yield a low permeability coefficient (<10^{-7} cm/s) for the impermeable layer and guarantee sufficient strength and durability (Dai and Jing, 2010). Recently, many local and foreign scholars studied the grout of the impermeable layer of a landfill and its characteristics (Cuevas et al., 2009; Nhan et al., 1996). However, satisfying the requirement on permeability and performance in retarding pollutants through the impermeable grout is difficult because leachate in the landfill contains complex components at high concentration and high osmotic pressure. The existing impermeable layer does not pose any treatment to the leachate-polluted soil, and the impermeable grout also requires high content, thereby producing resource waste. Therefore, an effective solution is needed to develop an economical and environmentally friendly impermeable grout (Lu et al., 2009).

Leachate-contaminated clay, clay curing agent, and cement were used as the major materials added to form grout for the impermeable layer of the landfill. Batch tests were conducted to study the strength, permeability, and retardation characteristic of concretion bodies. Furthermore, the curing mechanism of grout and the retardation mechanism of the concretion body were revealed.

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2. Experimental material and method

2.1. Experimental material

Silty clay was obtained from a subway construction site in Wuhan City. Its main mineral components and physical mechanical indexes are listed in Table 1. The mineral components of clay were determined by using D8 Advance X-ray diffractometer from Bruker Corporation, Germany. The physical mechanical test for the clay followed China's "Standard of Geotechnical Test Method." Light compaction method was used for the compaction test.

The leachate was obtained from two landfills (Changshankou and Chenjiachong) in Wuhan City. Their water quality indexes are shown in Table 2. The heavy metal concentrations in the leachate were determined by using Optima 4300DV ICP-OES from PerkinElmer, Inc., USA, and the pH value was measured by using PHSJ-3F pH meter from Shanghai Precision & Scientific Instrument Co., Ltd. COD and NH_3-N were determined through the potassium permanganate method and Nessler's reagent spectrophotometry, respectively.

The clay curing agent was developed independently, the main composition comprises of 45.37% SiO_2, 21.83% CaO, 12.94% Al_2O_3, 11.68% SO_3, 2.35% TFeO, etc., which were determined by using Axios advanced X-ray spectrofluorometer.

2.2. Preparation of leachate-contaminated clay

The clay was dried and ground, and then sieved through a 2 mm screen. The sieved clay was used for tests. The leachate was added to the clay until the water content reached 20%. The leachate and clay were then mixed evenly and the mixture was braised for 10 days under the standard curing conditions (20 ± 2 °C, 95% humidity) to allow the leachate and clay to reach the reaction equilibrium. The leachate-contaminated clay prepared with leachate from Changshankou was lightly polluted clay, whereas the other with leachate from Chenjiachong was heavily polluted clay.

2.3. Experimental methods

The experimental results in initial stage demonstrated that clay achieved the highest solidification effect and grout exhibited efficient groutability when content of the clay curing agent is ~10% of the cement and soil–water ratio is 1:1. Therefore, only the effects of cement content (15%, 20%, and 25%) and curing time (3, 7, 15, and 28 days) on various performances of the polluted clay grout were studied in this paper, in which the concentration of the clay curing agent was constant at 10% cement and the soil–water ratio was set at 1:1.

The leachate-contaminated clay, clay curing agent, cement, and tap water were weighed. The mixture was stirred for 10 min by using a mortar mill. The evenly stirred grout was poured into the mold and compacted on the vibrating table for 1 min under the frequency and amplitude of 48Hz and 0.5 mm. The molds were then stripped after 24 h, and the volume of the concretion bodies was measured. A soil cutter was used to trim the concretion bodies into a 5 cm high standard sample with 5 cm diameter, which was cured for different time under the standard curing conditions (20 ± 2 °C, 95% humidity).

Table 2
Characteristics of leachate used for test.

Parameters	Concentration	
	Leachate from Changshankou	Leachate from Chenjiachong
pH	8.03	5.82
COD	3625.5	22,080
NH_3-N	26.8	840
Pb	0.055	752.1
Zn	0.066	416.3
Cr	0.212	128.7
As	0	54.25
Cd	0.007	96.58
Cu	0.009	155.7

All parameters are expressed in mg/L except pH.

The leaching concentration of the heavy metal pollutants in the concretion bodies was determined through the toxicity characteristic leaching procedure (TCLP). Concretion body particles (100 g; <9.5 mm diameter) were weighed and placed in a 2 L extraction flask. The volume of the acetic acid solution (deionized water was used to dilute the 17.25 mL of analytically pure glacial acetic acid to 1 L) with pH value of 2.88 was measured according to the liquid–solid ratio of 20:1 (L/kg). The extractant was added, and the extraction flask was fixed on a rotatable oscillator. The rotation speed was adjusted to 30 ± 2 r/min, and the mixture was allowed to vibrate for 18 ± 2 h at 23 ± 2 °C. The mixture was filtered by using vacuum filtration equipment.

The unconfined compressive strength of the concretion bodies was tested by using WDW-20 universal testing machine from Ji Nan Zhongzheng Testing Machine Manufacturing Co., Ltd., and the compression speed during the test was controlled at 5 mm/min.

The permeability coefficient of the concretion bodies was determined according to the American Experiment Standard ASTMD 5084, where the constant head test was performed on a PN3230M flexible-wall permeameter from Geoequip Corporation, USA. The confining pressure of the sample was maintained at 100 kPa to ensure that the film clings to the sample and prevent the side leakage of the solution. The hydraulic gradient and room temperature were set at 150 and 25 °C, respectively. The test sample was presaturated by using tap water in the vacuum saturator for 24 h, and then tap water was used to conduct the penetration test until the permeability coefficient was stabilized. The leachate that flowed through the concretion body was collected, and the concentration of the pollutants in the collected leachate was measured to study the efficiency of the concretion bodies in retarding the pollutants in the landfill leachate under similar permeability testing conditions.

3. Results and analysis

3.1. Permeability coefficient of concretion bodies

Permeability is the main index used in evaluating the performance of the impermeable layer of a landfill. Fig. 1 shows the time-varying law of the permeability coefficient of concretion bodies at different cement dosages. The permeability coefficient decreased and became

Table 1
Basic physico-mechanical properties and mineral components of tested soil.

Water content/%	Natural density/(g/cm^3)	Specific gravity	Void ratio	Liquid limit/%	Plastic limit/%	Optimum moisture content/%	Grain-size distribution/%			Maximum dry density/(g/cm^3)
							sand	silt	clay	
20.78	1.89	2.72	0.74	41.6	21.8	19.5	3.45	62.27	34.28	1.72

Mineral composition/%

Quartz	Kaolinite	Illite	Montmorillonite	Albite
77.74	2.01	1.64	4.70	13.91