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Modified sewage sludge as temporary landfill cover material

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Abstract

In order to study the feasibility of modified sewage sludge as landfill cover material and its performance in a complex landfill environment, strength and hydraulic conductivity tests were conducted. The permeability requirements for daily and interim covers were analyzed first. Based on saturated-unsaturated seepage calculations, it is suggested that approximately 1.0×10^{-4} cm/s and 1.0×10^{-5} cm/s are the appropriate values for the hydraulic conductivities of daily and interim covers, respectively. The strength and permeability requirements of the mixtures, when used as an interim cover, can be met at a sludge:lime:cement:silt:tire-derived aggregate (TDA) weight ratio of 100:15:5:70:15. Results also demonstrate that the solid content ratio of modified sewage sludge, which should be greater than 60% when modified sewage sludge is used as a temporary cover material, is crucial to both strength and hydraulic performance. In addition, as the duration of soaking of modified sewage sludge in synthetic leachate increases, the unconfined compressive strength increases, and the hydraulic conductivity decreases slightly or fluctuates between 1.0×10^{-5} cm/s and 1.0×10^{-6} cm/s, still meeting the requirements for an interim cover. The reduction in hydraulic conductivity of modified sewage sludge under the effect of synthetic leachate, as well as the long-term and environmental performance of the modified sewage sludge, should be examined in future studies.

Keywords: Modified sewage sludge; Temporary cover; Hydraulic conductivity; Unconfined compressive strength; Soaking

1. Introduction

In China, the output of urban sewage sludge has been dramatically increasing year by year. However, sludge treatment and disposal technology has lagged behind. The publication *Report on Sludge Treatment and Disposal Market in China (2011)*, from www.h2o-China.com, pointed out that by 2010 the quantity of dewatered sludge was close to 22 million tons, of which 80% were not disposed of properly. Sludge contains a large quantity of pollutants, which may cause secondary pollution to the environment if handled improperly. On the other hand, in a sanitary landfill, a large amount of cover material is usually needed to cover the garbage, as required in *Technical Code for Municipal Solid Waste Sanitary Landfill* (CJJ 17–2004). Sludge can be used as an alternative to traditional cover materials such as soil. Furthermore, the pollution caused by sludge can be prevented in a closed landfill system. However, as sludge usually has relatively high water content and low strength, modifications are necessary to improve its mechanical properties if it is used as a cover material in landfills.

Cover systems can be divided into temporary cover (including daily cover and interim cover) and final cover, and, according to CJJ 17–2004, the upper limit of the hydraulic conductivity (k) for a final cover must be less than 1.0×10^{-7} cm/s. There is no specification of hydraulic conductivity for daily cover, as its main purpose is not to reduce the rain invasion. As for an interim cover, the hydraulic

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conductivity must be low enough to prevent the waste from being exposed to rain, but the value is not stipulated explicitly in CJJ 17–2004. However, in recent decades, suggestions given for the hydraulic standard of temporary covers have been controversial. Li et al. (2003) suggested that the hydraulic conductivity of a temporary cover in a bioreactor landfill be high enough to facilitate the recirculation of leachate, but not so high as to ensure uniform degradation and waste stability. Therefore, they recommended that the hydraulic conductivity be maintained at the order of 10^{-4} cm/s for a bioreactor landfill, but low enough for a traditional landfill to reduce the output of leachate. Some researchers have pointed out that the hydraulic conductivity of a temporary cover, like that of a final cover, should not exceed 10^{-7} cm/s (Ng and Lo, 2007; Chen et al., 2011). Kamon et al. (2002b) suggested that when sludge barrier layers have a hydraulic conductivity of less than 1.0×10^{-5} cm/s, daily cover systems intercept rainwater at a satisfactory level. Meanwhile, other researchers have argued that daily cover and municipal solid waste should be more permeable, or that they should have hydraulic conductivities greater than 1.0×10^{-4} cm/s. That way, standing water on the cover surface can be prevented (Ma et al., 2007; Jiao, 2007; Md and Mohamed, 2012). Zhang (2007) determined that soils with either high or low hydraulic conductivity are not suitable as interim cover materials, since soils with high hydraulic conductivity fail to control rainfall infiltration, and soils with low hydraulic conductivity might cause perched leachate. However, Zhang (2007) did not consider the effects of permeability of the daily cover and waste. Alternative daily cover materials are suggested in Standard Guide for Evaluation and Selection of Alternative Daily Covers (ADCs) for Sanitary Landfills (ASTM, 2005), including foams, spray-on slurries, geosynthetics, and indigenous materials (such as sludge, ash, and shredded tires), which have different levels of permeability. In general, the hydraulic conductivity of solid waste might vary between 3.7×10^{-5} cm/s and 4×10^{-2} cm/s, according to Qian et al. (2010). Therefore, consider the effects of permeability of the daily cover and waste on the leachate migration in landfills should be considered.

The properties of deeply dewatered sludge and modified sludge used as temporary landfill cover material have been studied by a number of researchers (Wang et al., 1992; Moo-Young and Zimmie, 1996; Kamon et al., 2002a; Kim et al., 2005; Jiao, 2007; Ma et al., 2007; Chen et al., 2011, 2013; Zhou et al., 2011). It has been found that sludge can be used as temporary cover material because of its strength, hydraulic performance, and capability of leaching toxicity. So far, the relevant studies have not given adequate concern to the effects of leachate on the properties of the temporary cover. In fact, during the operation and after the closure of a landfill, the temporary cover is soaked in the leachate. The interaction between cover material and leachate might change the properties of cover material, such as the strength and hydraulic conductivity. The effect of leachate on the hydraulic conductivity of clay liner has received much attention (Frempong and Yanful, 2008; Guyonnet et al., 2005). After deeply dewatered sewage sludge was soaked in de-aired water and leachate for one or two months, the strength was found to show a decreasing trend and the permeability an increasing one (Chen et al., 2011, 2013). In spite of these findings, there is still a lack of deep understanding of the interaction between leachate and modified sludge.

When used as landfill cover material, sludge is usually modified with cement, lime, slag, mineralized refuse, and construction waste (Kamon et al., 2002a; Kim et al., 2005; Jiao, 2007; Ma et al., 2007; Zhou et al., 2011). Silt and fly ash can be used as an additive to construct the skeleton (Li, 2006; Yang et al., 2012). As a light-weight material and good adsorbent of organic contaminants, tire-derived aggregate (TDA) has been mixed with paper sludge as a daily cover material to improve the quality of leachate and overall stability, and to reduce settlement of solid waste (Ng and Lo, 2007, 2010). Nevertheless, the hydraulic conductivities of such modified sludge are usually very low (generally around 1×10^{-7} cm/s) (Ng and Lo, 2007), which might make them unsuitable for daily cover. In this study, traditional modification materials (i.e., quicklime and cement) along with some waste materials (i.e., abandoned silt and TDA) were used in combination to alter the sludge properties.

One objective of this study was to determine the permeability value appropriate for temporary cover. The effects of hydraulic conductivity of interim and daily covers on the leachate migration were analyzed with unsaturated and saturated seepage software (SEEP/W). Another objective was to examine the strength and hydraulic performance of the modified sludge proposed in this study after soaking it in water and synthetic leachate. Based on the results of the study, the potential effectiveness of the proposed modified sludge as temporary landfill cover material is discussed.

2. Appropriate permeability for temporary covers

The finite element program SEEP/W was used to analyze the leachate migration through a landfill element. The simulation test was run in stages: initially, from a drainage layer, only the first waste discharge and daily cover were simulated, and, afterwards, the first interim cover, the second waste discharge and daily cover, and the second interim cover were added in turn. The thicknesses of the drainage layer, waste and daily cover, and interim cover were 0.4 m, 7.6 m, and 0.4 m, respectively. Each layer was deposited for one year before another one was input, and the total simulation time was four years.

Waste and daily cover was assumed to be a single homogeneous medium and buried instantaneously. According to the summary by Qian et al. (2010), the saturated hydraulic conductivity of the waste and daily cover layer were set to a minimum value (i.e., 3.7×10^{-5} cm/s), an average value (i.e., 1×10^{-3} cm/s), and a maximum value (i.e., 0.04 cm/s), respectively. A drainage layer with a saturated hydraulic conductivity of 1×10^{-2} cm/s was assumed to be located at the base of the waste. Saturated hydraulic conductivities of two interim covers were set to 1×10^{-5} and 1×10^{-6} cm/s for two simulations.