Available online at www.sciencedirect.com
ScienceDirect
Waste Management 28 (2008) 2635–2644
waste management
www.elsevier.com/locate/wasman

Analytical study on the suitability of using bentonite coated gravel as a landfill liner material

Anel A. Roberts *, Takayuki Shimaoka

Department of Urban and Environmental Engineering, Graduate School of Engineering, Kyushu University, 744 Motooka, Nishi-ku, Fukuoka City 819-0392, Japan

Accepted 29 January 2008
Available online 19 May 2008

Abstract

This study investigates the feasibility of using bentonite coated gravel (BCG) as a liner material for waste landfills. BCG has proven to be a very effective capping material/method for the remediation of contaminated sediments in aquatic environments. The concept of BCG is similar to that of peanuts/almonds covered with chocolate; each aggregate particle has been covered with the clayey material. Laboratory tests were aimed at evaluating regulated and non-regulated factors for liner materials, i.e., permeability and strength. Tests included X-ray diffraction, methylene blue absorption, compaction, free swelling, permeability, 1D consolidation, triaxial compression and cone penetration. The compactive efforts used for this study were the reduced Proctor, standard Proctor, intermediate Proctor, modified Proctor and super modified Proctor. The compactive energy corresponding to each effort, respectively, is as follows: 355.5, 592.3, 1196.3, 2693.3, and 5386.4 kJ/m^3. Results revealed that even though aggregate content represents 70% of the weight of the material, hydraulic conductivities as low as 6×10^{-10} cm/s can be achieved when proper compactive efforts are used. Compressibility is very low for this material even at low (or no) compactive efforts. Results also demonstrated how higher compactive efforts can lower the permeability of BCG; however, over-compaction creates fractures in the aggregate core of BCG that could increase permeability. Moreover, higher compactive efforts create higher swelling pressures that could compromise the performance of a barrier constructed using BCG. As a result of this study, moderate compactive efforts, i.e., intermediate Proctor or modified Proctor, are recommended for constructing a BCG barrier. Using moderate compactive efforts, very low hydraulic conductivities, good workability and good trafficability are easily attainable.

1. Introduction

Waste landfills are the final repositories for unwanted or unusable waste (Daniel, 1993). The design of engineered waste landfills involves the use of some sort of barrier(s) that will separate the buried waste from the groundwater system and the above ground environment during the operational and post-operational periods of the facility (USACE, 2003; Rowe et al., 2004). Liner technology and relevant regulations have evolved significantly in the past several decades (Edil, 2003). Most variations in landfill liner regulations focus on the required thickness of the liner, the materials used for lining, and the required permeability of the liner. Changes in liner regulations are the result of better understanding of the polluting characteristics of contaminants present in landfill sites. Therefore, it is of paramount importance to research new materials and design better innovative barriers systems for waste landfills that can, to a great extent, prevent the release of contaminants into the environment.

The objective of developing innovative barriers and barrier materials is to produce barriers that are more efficient and/or less costly than existing barriers. The improved efficiency refers to better performance in terms of containment or sustainability of containment (Shackelford, 2005).

Bentonite coated gravel (BCG) has proven to be a very effective capping material/method for the remediation of

* Corresponding author. Tel./fax: +81 92 802 3432.
E-mail address: roberts@doc.kyushu-u.ac.jp (A.A. Roberts).

0956-053X/$ - see front matter © 2008 Published by Elsevier Ltd.
doi:10.1016/j.wasman.2008.01.020

contaminated sediments in aquatic environments, see Section 3.1 (AquaBlok, Ltd., 1996). However as a landfill liner, BCG will have to comply with regulated and non-regulated aspects stipulated for landfill liners, i.e., permeability and strength, respectively. This paper assesses the suitability of using BCG as a landfill liner, and explores certain mineralogical and physical aspects of BCG visualizing a landfill scenario.

Contrary to the placement of BCG in aquatic environments, installation of BCG as a landfill barrier will require compaction; therefore, the focus of this study is on the effects of compactive effort on certain engineering characteristics of BCG, i.e., permeability and strength.

2. Literature review

Many different factors will affect the performance of BCG as a landfill liner. One of these affecting factors is the compaction of BCG during construction of the barrier. It is well known that to improve the performance of soil hydraulic barriers in engineered waste landfills, e.g., compacted clay liners (CCL), compaction is widely used for re-arranging soil particles in order to obtain a smoother, more homogeneous layer free of large interconnecting voids.

Factors influencing the fabric of compacted clay are: water content during compaction, method and effort used for compaction, clod size(s) of clay, and the thickness and interlocking of layers (Bagchi, 2004). It is well known that higher compactive efforts and slightly higher water contents, i.e., above optimum, can lower the permeability of selected soils (Mitchell et al., 1965). Mitchell et al. (1965) categorized water content and compactive efforts as the critical factors affecting the hydraulic conductivity of compacted clays. They demonstrated that the hydraulic conductivity of CCL can be greatly reduced either by increasing the compactive effort or by increasing the moisture content 2–4% above optimum water content (ω_{opt}). Many researchers in this field have obtained similar results, e.g., Benson and Daniel (1990), Daniel and Benson (1990), Shelley and Daniel (1991), Benson et al. (1994), Attom (1997), Mizuno et al. (2005), Mohamedzein et al. (2005).

Another factor to consider when constructing landfill soil barriers is the presence and amount of aggregate. Published studies have shown that at high aggregate contents, i.e., more than 60%, the permeability of compacted soils tends to increase (Holtz and Lowitz, 1957; Garga and Madureira, 1985; Shelley and Daniel, 1991; Tinjum et al., 1997). Holtz and Lowitz (1957) indicated that an increase in permeability of soils containing high aggregate content can be accredited to interference of the gravel portion on the proper compaction of the finer material. Furthermore, when the gravel portion exceeds two-thirds of the total material, there is insufficient finer material to fill the voids between the aggregate particles. These two factors result in a higher void ratio that increases the permeability of the soil. Garga and Madureira (1985) conducted large-scale field and laboratory tests in order to investigate the compaction characteristics of river terrace gravel. Their conclusions stated that the maximum density for a specific compaction effort is obtained at gravel contents of 65–70%. Shelley and Daniel (1991) showed how soils such as mine spoil or kaolonite mixed with gravel at contents as high as 60% can achieve low hydraulic conductivities, i.e., $k \leqslant 1 \times 10^{-7}$ cm/s; however, beyond 60% gravel content the permeability of both soil mixtures increased rapidly. It should be noted that the above mentioned studies were conducted using little or no expansive clays. The ability of expansive clays to swell, fill the void and lower the permeability of the barrier is well understood.

Based on studies concerning the effect of aggregate content on the permeability of soils, such as the ones presented here and others, recommendations for constructing landfill soil liners indicate that the amount of gravel should remain below 30–50% by unit weight of the barrier (USEPA, 1999; Shelley and Daniel, 1991; Daniel, 1993). It is important to indicate that these recommendations – or at least those presented by Shelley and Daniel (1991) and Daniel (1993) – are based not on the amount of gravel content itself, but on the assumptions that: (1) it will be very difficult to obtain a proper distribution of the gravel and the matrix material during construction of the barrier in the field; and (2) higher gravel contents can produce segregation of the gravel causing pockets; and this is likely to occur during construction of the barrier. However, the question remains on the performance of soils with high gravel content mixed with highly expansive clay, as is the case of BCG.

3. Material

3.1. Material background

BCG is shown in Fig. 1a. This is a composite-aggregate technology that consists of a dense core comprised of gravel aggregate and a shell comprised of clay or clay sized materials – often bentonite – and polymers. The concept of BCG is similar to that of peanuts/almonds covered with chocolate. Each aggregate particle is covered with the clayey material. Fig. 1b shows the cross-section of a typical BCG particle. BCG was primarily designed to act as capping materials for contaminated sediments in aquatic environments. The function of the aggregate core is to act as a sinker that will deliver reactive clay components through a column of water and settle over the contaminated sediments. After settling, the clay components will swell to form a cohesive low hydraulic conductivity barrier between the contaminated sediment and the surrounding water ecosystem, allowing isolation, stabilization and/or ease removal of the contaminated sediment. However, in a landfill scenario, the function of the aggregate core will be mainly to support the vertical burdens impose by other barrier components, layers of daily refused and cover soil. Fig. 1c shows a typical BCG particle in its dry stage. Fig. 1d shows hydrated uncompacted particles.