Applied Clay Science 97-98 (2014) 200–214

Contents lists available at ScienceDirect

Applied Clay Science

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

Research paper

Evaluation of gas permeability and mechanical behaviour of soil barriers of landfill cap covers through laboratory tests

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ARTICLE INFO

Article history:
Received 19 November 2011
Received in revised form 26 December 2012
Accepted 29 April 2014
Available online 25 June 2014

Keywords:
Landfills
Municipal solid waste
Waste containment systems
Soil barrier
Gas permeability
Fibre reinforcement

ABSTRACT

The soil barrier is one of the commonly used impervious barriers which are required to sustain deformation and prevent the migration of biogas to the atmosphere. In the present study, a simple custom designed gas permeability–bending test setup was developed and used to evaluate the deformation behaviour of the soil barrier material in-relation with gas permeability measurements. A series of conventional beam bending tests, unconfined compression tests and gas permeability–bending tests was performed to evaluate the influence of loading pattern, compaction characteristics and fibre reinforcement on the deformation behaviour of the soil barrier material. The experimental results reveal that loading pattern was not found to have any significant influence on the flexural tensile strength of the soil; however, a considerable influence on the displacement corresponding to gas breakthrough was noticed mainly due to the variation in the cracking pattern. An increase in the moulding moisture content of the soil leads to a significant delay in crack initiation and gas breakthrough with a slight reduction in the flexural tensile strength. The percentage increase in the flexural tensile strength of the soil beam compacted with 2% and 4% wet of optimum, upon inclusion of fibres was found to be 33% and 92% respectively. Similarly, the percentage increase in the limiting displacement of the soil moist-compacted at 2% and 4% wet of optimum, upon inclusion of fibres was found to be 30% and 25% respectively, which implies that soil reinforced with fibres can sustain its integrity in-terms of gas intactness up to relatively larger distortion than an unreinforced soil barrier material. The performance of the deformation behaviour of the soil barrier material has significantly improved in-terms of flexural tensile strength and gas intactness upon inclusion of discrete fibre inclusions within the soil.

1. Introduction

The fugitive emissions of landfill gas to the atmosphere are one of the major environmental issues related to municipal solid waste landfills. Landfill gas (LFG or biogas) is roughly composed of 60% methane (CH_4), 40% carbon dioxide (CO_2) and more than 150 trace compounds (Reinhart and Townsend, 1997). Both methane and carbon dioxide are greenhouse gases that contribute actively to global climate change. The global warming potential of carbon dioxide is equal to 1 compared to 25 for methane, which implies that methane emission has an environmental impact 25 times higher than CO_2 (IPCC, 2007). Fig. 1 shows the fate of methane from its production to its emissions or collection. The generation of methane within MSW landfills begins with the phase of anaerobic degradation after the waste dumping and extended until the end of biodegradation during post-operation, after-care and long-term custodial care of the landfill management system (Staub et al., 2011). The total amount of biogas generated could be greater than 200 m^3 per ton of waste depending of the composition of MSW. The generated methane can be collected by wells, horizontal pipes into the waste body and gas drainage layer beneath the cap cover of the landfill and then it could be either flared or used to generate electricity and/or heat. Flares simply convert methane to carbon dioxide and hence reduce potential methane emissions drastically. The uncollected methane may be partially oxidised in the top soil of the permanent or the final cap cover (Staub et al., 2011).

Landfill cap covers constitute the cap barrier in the form of a compacted clay liner (CCL), amended soil, geomembranes, geosynthetic clay liners, polymer amended sand–bentonite barriers or combination of these (composite liner) which could minimise the infiltration of rain water and stop or rather mitigate the fugitive methane emissions. Compacted fine-grained soils are commonly used as a cap barrier in

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http://dx.doi.org/10.1016/j.clay.2014.04.041
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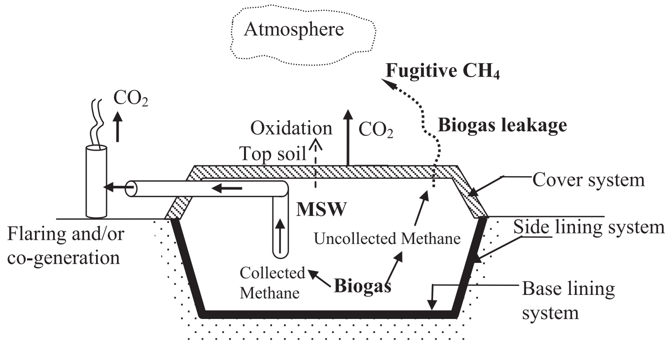

Fig. 1. Methane from its production to its emission, oxidation and recovery.

areas where these types of soils are economically available at construction sites (Gourc et al., 2010a; Heerten and Koerner, 2008). Cap barrier layer must be capable of limiting the gas flow, in addition to limiting infiltration of water. As a result, it is necessary to evaluate the effectiveness of the cap barrier as a gas barrier. Figueroa and Stegmann (1991) performed several field tests on a 0.6 m thick soil cover at a German landfill. The landfill gas flow rate ranged from 5.2×10^{-6} to 9.6×10^{-5} $m^3/m^2/s$. It was also mentioned that if cracks formed in the cap barrier due to desiccation or differential settlements, the flow rate of biogas could increase significantly.

The biodegradation of municipal solid waste within landfills can lead to the generation of biogas and reduction in the thickness of waste mass, and can induce significant settlement to the cap cover (Gourc et al., 2010b). The inevitable heterogeneity of MSW can induce differential settlements, as shown in Fig. 2. Several researchers experimentally found that the possibility of cracks in cap barriers due to distortion/differential settlements cannot be ruled out in landfill cap covers. When the induced tensile strain due to differential settlements exceeds the ultimate tensile strain of the cap barrier material, it may lead to cracks in the tension zone, as shown in Fig. 2. The cracking of the cap barrier can lead to a drastic increase in its hydraulic conductivity, thereby, increasing the rainfall infiltration through the cover system. In addition, cracking of the cap barrier can also lead to the fugitive emissions of biogas which can cause a serious environmental hazard. Hence, cracking of the cap barrier may fail to perform its basic functions (i.e., ensuring safe biogas collection and mitigating seepage of water through the barrier). Hence, the motivation of the present study is to assess the deformation behaviour of the clay based cap barrier material in-relation with the gas permeability under various stages of differential settlements. It is worth to mention that the priority in the optimisation of the cap barrier is to have higher deformability rather than achieving higher mechanical strength.

The behaviour of the cap barrier at the onset of deformation can be analysed by analytical, numerical or physical modelling approaches. Many researchers adopted physical modelling approaches to understand the deformation behaviour of cap barriers by choosing field or centrifuge modelling testing methods (Gourc et al., 2010a; Rajesh and Viswanadham, 2010; Viswanadham and Rajesh, 2009). Few researchers performed beam bending tests mainly because it represents the deformation behaviour of the landfill cap cover subjected to deformation. In addition, it can also provide the flexural tensile strength of the soil barrier material. Gas permeability of the cap barrier material has been determined by few researchers using steady state, un-steady state and/or falling head approaches (Li et al., 2004; Moon et al., 2008). Even though few researchers evaluated the initial gas permeability of the cap barrier material, not many attempts were made to understand the variation in the gas permeability of the cap barrier under deformation. Hence, in the present study, a simple custom designed gas permeability–bending (gas k–bending) test setup has been developed to measure the gas permeability of the moist-compacted soil beam at the onset of deformation in the laboratory. The influence of loading pattern, compaction characteristics and strengthening measures in the form of discrete fibre reinforcement on the flexural tensile strength and gas permeability was also explored and discussed.

2. Materials and methods

2.1. Model materials

The soil used in the present study is a commercially available soil which has a major portion of kaolinite mineral. The physico-chemical properties of the chosen soil sample are given in Table 1. The soil sample was found to have a liquid limit of 48% and plasticity index of 21% with a soil classification of CL, as per USCS. The maximum dry unit weight and optimum moisture content (OMC) were found to be 15.4 kN/m^3 and 23.2% respectively (standard Proctor compaction test). The hydraulic conductivity of the soil specimen compacted at its maximum dry unit weight and OMC was found to be 1.2×10^{-9} m/s. The property of the chosen soil barrier material represents bandwidth geotechnical

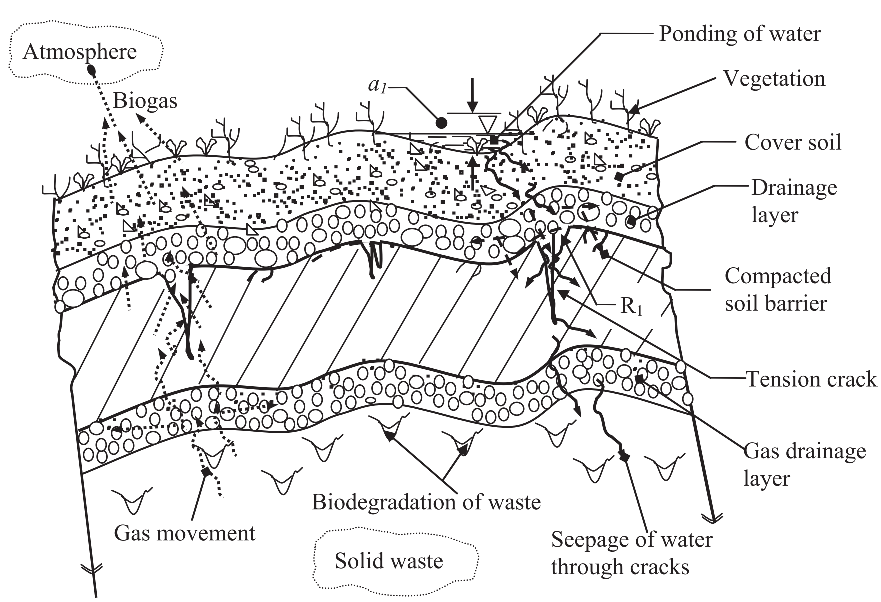

Fig. 2. Schematic representation of deformation behaviour of soil barrier of a cover system subjected to differential settlements.