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Engineering properties for high kitchen waste content municipal solid waste

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ABSTRACT

Engineering properties of municipal solid waste (MSW) depend largely on the waste's initial composition and degree of degradation. MSWs in developing countries usually have a high kitchen waste content (called HKWC MSW). After comparing and analyzing the laboratory and field test results of physical composition, hydraulic properties, gas generation and gas permeability, and mechanical properties for HKWC MSW and low kitchen waste content MSW (called LKWC MSW), the following findings were obtained: (1) HKWC MSW has a higher initial water content (IWC) than LKWC MSW, but the field capacities of decomposed HKWC and LKWC MSWs are similar; (2) the hydraulic conductivity and gas permeability for HKWC MSW are both an order of magnitude smaller than those for LKWC MSW; (3) compared with LKWC MSW, HKWC MSW has a higher landfill gas (LFG) generation rate but a shorter duration and a lower potential capacity; (4) the primary compression feature for decomposed HKWC MSW is similar to that of decomposed LKWC MSW, but the compression induced by degradation of HKWC MSW is greater than that of LKWC MSW; and (5) the shear strength of HKWC MSW changes significantly with time and strain. Based on the differences of engineering properties between these two kinds of MSWs, the geo-environmental issues in HKWC MSW landfills were analyzed, including high leachate production, high leachate mounds, low LFG collection efficiency, large settlement and slope stability problem, and corresponding advice for the management and design of HKWC MSW landfills was recommended.

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1. Introduction

Landfill is the principal treatment of municipal solid waste (MSW) because it is both low cost and sorting-free (Chen et al., 2010a; EPA, 2013). The design and security service of landfills have been challenged due to the complicated behaviors and unknown aspects of MSW's geotechnical properties (Machado et al., 2010). The design and stability assessment of slopes relate to the shear strength, hydraulic conductivity and vertical compressibility of the MSW. The leachate collecting system design is influenced by water content, field capacity, and hydraulic conductivity of the MSW. Additionally, the design of the landfill gas (LFG) collection and air injection system depends on the gas permeability of the MSW and the potential LFG capacity. It is difficult to fully characterize the engineering properties of MSW as the heterogeneous ones, but it is important to understand the basic behaviors and key engineering properties of MSW to enable the effective management and design of MSW landfills (Dixon and Jones, 2005).

Developed countries have performed numerous studies on MSW engineering properties. Landva and Clark (1990) carried out a research on the stability of landfills and explored the behaviors of MSW, including composition, unit weight, permeability, compressibility and shear strength. Gabr and Valero (1995) conducted a geotechnical testing program to evaluate the waste properties (such as specific gravity of solids, water and organic contents, and composition) and the engineering properties such as permeability, compressibility and shear strength of aged MSW retrieved from the Pioneer Crossing Landfill located in Pennsylvania, USA.

In terms of hydraulic conductivity of MSW, Powrie and Beaven (1999) and Beaven (2000) used a large-scale compression cell to study the relationships between MSW's hydraulic conductivity and density, effective porosity, and effective stress. Many researchers (Landva and Clark, 1990; Shank, 1993; Jain et al., 2005; Reddy et al., 2009a,b,c; Beaven et al., 2011) implemented field tests to measure the field hydraulic conductivity of MSW.

With respect to MSW's gas permeability, a short-term air injection test was conducted by Jain et al. (2005) at New River Regional Landfill in Florida, USA to investigate and evaluate the impact of waste depth and the effect of leachate recirculation on air

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permeability. Additionally, gas flow and transport models were used to estimate the gas diffusivity and permeability of MSW (Jung et al., 2011; Larson et al., 2012).

Considering the difference of compressibility between MSW and soil, Wall and Zeiss (1995) studied the effects of MSW's biodegradation on settlements. They also constructed landfill test cells to model both compression and decomposition over extended periods. Manassero et al. (1996) summarized the mechanisms resulting in the compression of MSW and analyzed the factors affecting the magnitude of settlement. Researchers maintained substantial interests in the compressibility of MSW and conducted various laboratory tests or numerical modeling (Landva et al., 2000; Hossain et al., 2003; Reddy et al., 2009b,d; Bareither et al., 2012a).

To gain insight into the shear strength of MSW, direct simple shear, direct shear and triaxial tests were conducted, and the effects of waste composition, confining stress, loading rate, degradation, samples size and strain on shear strength were explored in the past several years (Vilar and Carvalho, 2004; Harris et al., 2006; Kavazanjian, 2008; Zekkos et al., 2010; Reddy et al., 2009a,d; Bareither et al., 2012b).

Researchers in developing countries also conducted a vast number of studies on MSW. Based on the drilled MSW samples originating from the Qizishan Landfill in China, Zhan et al. (2008a,b) and Chen et al. (2009) measured WSM parameters such as composition, unit weight and void ratio, and explored engineering properties of MSW such as shear strength and compressibility. Wu et al. (2012a,b) conducted short-term air and water injection tests at a landfill in Beijing, and obtained the field air permeability and hydraulic conductivity of MSW. Machado et al. (2010) conducted a number of tests at two Brazilian landfills, and evaluated the parameters such as water and organic contents, composition, permeability and shear strength.

These studies revealed that the engineering properties of MSW depend not only on the waste's composition, but also on its degree of degradation (Dixon and Langer, 2006; Zhan et al., 2008a; Chen et al., 2009; Machado et al., 2010; Zekkos et al., 2010; Bareither et al., 2012a,b). MSWs from developed and developing countries are significantly different; for example, Chinese MSW contains largely kitchen waste with the content of over 50% (Chen et al., 2010a), which is called high kitchen waste content (HKWC) MSW. However, kitchen waste only accounts for 20% or less of the USA MSW (Staley and Barlaz, 2009), which belongs to the low kitchen waste content (LKWC) MSW. Furthermore, the kitchen waste degrades faster than the other compositions of MSW, which contributes to the differences of engineering properties between HKWC and LKWC MSWs.

Because the HKWC MSWs in developing countries are different from the LKWC MSWs in developed countries, the management or design principles used in developed countries may not be entirely applicable to landfills in developing countries. Therefore, a systematic comparison of the engineering properties between HKWC and LKWC MSWs should be performed, which is valuable for the design of HKWC MSW landfills.

In this paper, laboratory and field testing results of physical composition, hydraulic properties, gas generation, gas permeability, and mechanical properties for HKWC and LKWC MSWs are compared and analyzed. This work reveals the differences of engineering properties between HKWC and LKWC MSWs. Based on these findings, geo-environmental issues in HKWC MSW landfills are analyzed, and corresponding advice for the management and design of HKWC MSW landfills is recommended.

2. Physical and chemical components of fresh MSW

2.1. Physical composition of fresh MSW

Physical compositions of fresh MSWs from landfills in China, Brazil, USA and Canada are summarized in Table 1, as well as the

Table 1
Physical compositions of fresh MSWs and their initial water content (by wet basis, %).

Landfill/Country	Organic fractions				Inorganic fractions			Initial water content (IWC)
	Kitchen waste	Paper and cardboard	Textiles and leather	Wood	Plastics	Metals	Others	
SQL/China[a]	62.63	10.89	4.18	0.86	18.59	0.24	2.61	61[m]
CCL/China[b]	50.31	12.81	1.66	0.79	12.47	0.33	21.63	58[m]
SLL/China[c]	70	8	2.8	0.89	12	0.12	6.19	56[m]
BL/Brazil[d]	49.7	15.1	3.5	4.1	20.9	5.6	1.1	NA
MCL/Brazil[d]	42.9	19.7	4.5	5.2	18.7	1.5	7.5	50
OHL/USA[e]	6.9	24.6	5.8	11.7	11	4.4	35.6	31
NJL/USA[f]	18.6	26.7	0	13.5	8.9	4	28.3	18
SSL/Canada[g]	10.5	58	5.25	8.5	4.9	3.35	9.5	9
China[h]	55	9.9	3	2	15	0.5	14.6	52[m]
USA[i]	13.6	35.5	4.6	3.4	13.2	6.9	22.8	18
Canada[j]	27	26	2	2	8	1.5	33.5	NA
UK[k]	25	31	5	0	8	23	32	32
France[l]	28.6	26.8	5.7	3.3	11.1	4.1	20.4	NA

Note: Others include glass, ash, stone, brick and miscellaneous items; NA – not available.
[a] SQL denotes the Suzhou Qizishan Landfill (Zhang, 2007).
[b] CCL denotes the Chengdu Chang'an Landfill (Xue et al., 2008).
[c] SLL denotes the Shanghai Laogang Landfill (Gao et al., 2000).
[d] BL denotes the Bandeirantes Landfill and MCL denotes the Metropolitan Center Landfill (Machado et al., 2010).
[e] OHL denotes the Orchard Hills Landfill (Reddy et al., 2009a).
[f] NJL denotes the New Jersey Landfills, average data from all of 21 New Jersey Landfills, and IWC was estimated based on the water content of sorted fractions (Hull et al., 2005).
[g] SSL denotes the Spyhill Sanitary Landfill, average composition of waste streams in winter and summer, and IWC was estimated based on the water content of sorted fractions (Saint-Fort, 2002).
[h] Chen et al. (2010a).
[i] Staley and Barlaz (2009), average data of characterization studies in 11 states, and IWC was estimated based on the water content of sorted fractions.
[j] Assamoi and Lawryshyn (2012).
[k] Patumsawad and Cliffe (2002).
[l] Francois et al. (2007), food and garden wastes were considered as kitchen waste.
[m] Lan (2012).

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