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Influence of composition and degradation on the shear strength of municipal solid waste

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ABSTRACT

This study aimed to evaluate the shear strength of municipal solid waste (MSW) of different landfilling ages exhumed from disposal sites in a subtropical humid environment. Wastes which had been landfilled from ages of 2 up to 25 years were characterized using physical, chemical and biochemical tests and were tested in a large scale direct shear device. The results indicate that the tested wastes older than five years had reached similar decomposition stages, but showed different compositions in terms of soft plastics, incompressible material and reinforcing elements. Different composition was also noticed between less degraded and more degraded samples. In the former, the soil-like materials, that is the particles smaller than 19 mm, are essentially reinforcing components while in the later it is formed mainly by incompressible components. Although MSW composition did not vary significantly throughout the years, some difference in the originally landfilled waste could account for the observed variations. However, they are mainly the result of exhuming and preparation methods, whose influence is discussed in the paper, as well as the waste degradation state. The reinforcing components, rather than the soft plastics content, correlated well with cohesion intercept increase, both for the less and more degraded waste samples. The results also indicate that as MSW degrades the waste material evolves from an initially highly cohesive material to one that loses cohesion yet gains in shear strength angle over time.

1. Introduction

Landfills continue to be a key component of municipal solid waste (MSW) management. These engineered structures demand careful design especially in areas related to slope stability. Determining the shear strength of waste, an unusual construction material, is achieved through back analysis of failed slopes and by performing field and laboratory tests. As far as laboratory tests are concerned, MSW stress-strain behavior obtained from triaxial tests is usually strain hardening so no clear sign of failure is observed for the common range of strain attained in these tests. This behavior is credited to the mobilization of reinforcing elements usually present in MSW, such as plastics. In direct shear tests the stress-strain behavior is also usually strain hardening, yet some stress-displacement curves concave downwards and depending on the displacement range reached in the test a peak shear stress can be attained. The mobilization of reinforcing elements is believed to be less intensive in these tests, as the main reinforcing components are parallel to the shearing plan due to sample compaction.

For the interpretation of both tests shear strength parameters are commonly derived utilizing the Mohr Coulomb shear strength criteria and strain compatibility with other elements of the structure. Reported values of MSW shear strength parameters determined from direct shear tests are friction angles (φ) ranging from 0 to 50° and cohesion intercept (c) values ranging from 27 to 41 kPa (Bray et al., 2009). This large range may be due to waste's heterogeneous nature, difficulty in recovering and testing representative waste samples and a lack of standardized testing procedures designed specifically for waste materials. In addition, climate, landfill operation practices and waste composition are known to influence the geotechnical behavior of landfill masses, which makes comparing results from different sites even more challenging.

The decomposition of biodegradable components of MSW to CH_4 and CO_2 in landfills is well documented (Barlaz et al., 1989; Christensen and Kjeldsen, 1995). However, the changes to MSW shear strength because of its compositional and structural evolution over time are still largely unknown and remain a controversial subject (Bray et al., 2009; Stoltz et al., 2009). For instance,

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Turczynski (1988), Caicedo et al. (2002), Gabr et al. (2007a,b), Varga et al. (2011), Hossain and Haque (2009) and Reddy et al. (2009a) found that MSW shear strength diminishes as MSW gets "older". Zhan et al. (2008) concluded just the opposite, while Reddy et al. (2011) and Koerner and Koerner (2015) stated that MSW starts as a high friction material and evolves into a material that loses friction yet gains cohesion over time. On the other hand, Zekkos (2005) concluded that there is no significant change in MSW shear strength over time Bareither et al. (2012) argued that the initial waste composition and subsequent changes to that composition are more relevant to MSW shear resistance than the state of decomposition itself.

Sometimes the terms MSW age and MSW degradation are interchangeably used. However, the fact that a waste has been buried for more time does not imply that it is more degraded than waste that has recently been deposited. A number of factors limit the decomposition of biodegradable components in landfills, including environmental conditions such as moisture, pH, and temperature (Barlaz et al., 1990), as well as initial waste composition and operational conditions of the disposal site, such as compaction efforts and leachate and gas drainage efficiency.

This paper presents the results of large-scale direct shear tests performed on MSW samples of different landfilling ages, exhumed from disposal sites in São Carlos, Brazil, and addresses the influence of the sample collection method and sample preparation procedure on the final composition of the tested specimens and on waste shear strength.

This study aimed to investigate the effects of waste degradation on MSW shear strength of selected samples that typify the waste streams, landfill operation conditions and climate of the Southeast states of Brazil, where humid subtropical conditions prevail and where organic waste is the largest fraction of the delivered waste. Because the entire degradation history and the initial composition of the wastes tested are not precisely known, chemical and biochemical tests were performed to characterize the state of degradation of the exhumed waste.

2. Materials and methods

2.1. Sample collection

Six samples with different landfilling ages were studied in this investigation. They were exhumed from three different disposal sites: an experimental landfill, a dumpsite and a sanitary landfill located in São Carlos, in southeastern Brazil, and were named per their landfilling year: S1988, S1995, S2001, S2004, S2007 and S2011. Shallow samples were collected in trenches and deeper samples were collected using hollow stem augers. The drill bit diameter of the auger was 35 cm or 29 cm, depending on the borehole.

The landfilling year was determined both from the site history obtained from site personnel, official documents and aerial photos and from dates still available on some of the exhumed packages. Table 1 summarizes the landfilling age and the recovery characteristics of the studied samples.

The gravimetric composition of MSW through the years can be appreciated in Table 2, which presents two surveys: one performed with waste from the experimental landfill, corresponding with sample S1988 and the other from the sanitary landfill, performed in 2006.

2.2. Sample preparation and characterization tests

Waste samples were exhumed and thoroughly mixed. The components longer than 200 mm were weighted and discarded from the sample during field work. After the first removal, the samples were quartered and subdivided. Thirty to 50 kg were extracted to determine the waste gravimetric composition. Fig. 1 summarizes the subsample extraction steps performed in this study.

The subsamples extracted for determining the waste gravimetric composition were screened through a 19 mm screen (wet sieving) and the retained components were separated by hand into the following categories: soft plastics, hard plastics, wood, tissues, metal, stones, rubber, paper, glass, other. The components that passed the 19 mm screen were aggregated into a single waste category and called "soil-like" material. All the components were then dried to constant weight at 60 °C and weighted. The gravimetric composition was calculated based on the dry weight.

About 300–500 kg of each exhumed sample were separated for the direct shear testing program. Based on the recommendations of Bray et al. (2009) and Athanasopoulos (2011) and owing to the dimensions of the direct shear testing device, the maximum particle size allowed for testing was 85 mm. Therefore a second hand sorting was performed on these subsamples to remove the particles that were longer than 85 mm. In samples S2001, S2004 and S2007 about 72–74% of the recovered waste remained to be tested after sample preparation procedures, while in samples S1988, S1995 and S2011 these percentages were 57%, 57% and 47% respectively.

Four kilo of each sample prepared for mechanical tests were extracted for the grain size analysis, which was performed after drying the waste at 60 °C. 3 kg of the soil-like material were extracted for chemical and biochemical tests. The remaining waste was used for mechanical tests.

The chemical and biochemical tests performed to quantify the degradation of the waste samples were loss on ignition (LOI), total organic carbon (TOC), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD) and dissolved organic carbon (DOC). Abreu and Vilar (2016) presented the details of these characterization procedures, which are summarized here.

TOC and LOI tests were performed on solid samples, with measurements completed in triplicate on each waste. To perform the LOI tests the following non-biodegradable components were hand sorted and excluded from the sample: plastics, metals and stones. For the LOI test subsamples weighting between 50 and 100 g were dried until constant weight at 60 °C for one hour and then burned

Table 1
Landfilling age of the tested samples, operational conditions of the disposal site, method and depth of recovery.

Sample	Landfilling age (years)	Sample depth (m)	Sample wet mass (kg)	Recovery method	Operational conditions of the disposal site
S1988	25	1.0–1.5	900	Trench	Experimental landfill. Cover: 40 cm clayey sand + hypalon membrane + 30 cm clay layer; Drainage: gas and leachate;
S1995	16	0.7–1.5	1500	Trench	Dumpsite. Cover: 40 cm clayey sand
S2001	11	16–19	530	Borehole	Controlled landfill. Cover: compacted clayey sand; some gas and leachate drainage system
S2004	8	11–14	500	Borehole	
S2007	5	7–9	520	Borehole	Sanitary landfill. Cover: geomembrane + compacted clayey sand; gas and leachate drainage system
S2011	2	1.0–1.3	600	Trench	

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