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Utilization of sepiolite materials as a bottom liner material in solid waste landfills

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ABSTRACT

Landfill bottom liners are generally constructed with natural clay soils due to their high strength and low hydraulic conductivity characteristics. However, in recent years it is increasingly difficult to find locally available clay soils that satisfy the required engineering properties. Fine grained soils such as sepiolite and zeolite may be used as alternative materials in the constructions of landfill bottom liners. A study was conducted to investigate the feasibility of using natural clay rich in kaolinite, sepiolite, zeolite, and their mixtures as a bottom liner material. Unconfined compression tests, swell tests, hydraulic conductivity tests, batch and column adsorption tests were performed on each type of soil and sepiolite–zeolite mixtures. The results of the current study indicate that sepiolite is the dominant material that affects both the geomechanical and geoenvironmental properties of these alternative liners. An increase in sepiolite content in the sepiolite–zeolite mixtures increased the strength, swelling potential and metal adsorption capacities of the soil mixtures. Moreover, hydraulic conductivity of the mixtures decreased significantly with the addition of sepiolite. The utilization of sepiolite–zeolite materials as a bottom liner material allowed for thinner liners with some reduction in construction costs compared to use of a kaolinite-rich clay.

1. Introduction

Compacted clay liners located below the municipal solid waste are one of the most important parts of the landfills. The primary duty of these liners, sometimes referred to as bottom liners, is acting as a hydraulic barrier to prevent leaching of inorganic and organic pollutants (which is leaching from municipal solid waste in the landfills) into the groundwater or surface water. Hydraulic conductivity and strength of a typical liner material used in the landfill should not be less than 1×10^{-9} m/s and 200 kPa respectively (Daniel and Benson, 1990; Guney et al., 2008; Osunibu and Nwaiwu, 2006; Kang and Shackelford, 2010; Fransisca and Glatstein, 2010). Liners are usually constructed with locally available clay soils due to their high unconfined compressive strength and low hydraulic conductivities (Kayabali, 1997). However, in recent years it has become harder to find locally available natural soil that satisfies the engineering properties mentioned above. Therefore, researchers seek alternative materials that may be used as a liner in municipal waste landfills. Recent studies have proposed replacing natural clay soils with soil-like geomaterials such as sand–bentonite mixtures, foundry sand, fly ash, wood ash, and fly ash amended tire rubber (Kenney et al., 1992; Pandian et al., 1996; Palmer et al., 2000; Abichou et al., 2004; Akgun, 2010).

Constructing liners with such alternative materials can provide significant money savings since most of these alternative materials can be obtained at a marginal cost (Cetin et al., 2010). Even though these materials generally satisfied the engineering properties that are needed to be used in liner constructions, issues pertinent to their mechanical and environmental suitability have been reported. For instance, Edil et al. (1992) and Palmer et al. (2000) suggested that utilization of fly ashes in liner construction is feasible. However, compaction process of fly ashes in the field can be difficult and may yield higher hydraulic conductivity and lower stiffness (Palmer et al., 2000). In addition, fly ash itself contains a high amount of heavy metals which poses an additional environmental concern (Goswami and Mahanta, 2007; Morar et al., 2012; Cetin et al., 2012). Sand–bentonite mixtures and foundry sand provided reasonable stiffness and hydraulic conductivity values with pure deoinized water influent solutions. However, the hydraulic conductivity of these soils increased significantly when chemical influent solutions were used (Abichou et al., 2004).

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High metal adsorption capacity of natural clay is one of their selection in landfill liner construction. Sepiolite and zeolite are two good alternative materials for natural clay soils. Sepiolite is a natural clay mineral ($Mg_4SiO_6O_{15}(OH)_2{\cdot}6H_2O$) with fibrous morphology and intracrystalline channels (Dogan et al., 2009; Giustetto et al., 2011). Sepiolites are very abundant in Turkey and can be obtained at a low cost (Alkan et al., 2004; Guney et al., 2008; Dogan et al., 2009). Sepiolite has high specific surface area and high surface activity that allow for higher adsorption capacity of heavy metals (Alkan et al., 2004; Eren and Ozbay, 2010). It has many molecular sized channels that increase the available surface areas in the sepiolite materials so metals can easily be attached (Dogan et al., 2009; Giustetto et al., 2011).

Zeolite materials also have high metal adsorption capabilities especially for divalent cations (Svilovic et al., 2009). Zeolite is often used in many environmental remediation processes, including waste water treatment, removal of toxic metals, and chlorinated phenols from aqueous media (Elsayed-Ali et al., 2011). High ion-exchange properties of zeolite yields high metal adsorption capacity in the zeolite materials (Qin et al., 2010). It is possible to entrap the heavy metals and prevent them moving toward to the groundwater or surface water in landfills by utilizing the zeolite in the liners (Elsayed-Ali et al., 2011).

The main objective of this study was to investigate the mechanical and environmental suitability of sepiolite–zeolite soil mixtures as a landfill liner material. To achieve this objective, a series of geomechanical and environmental laboratory tests were conducted on sepiolite, zeolite, sepiolite–zeolite mixtures and on natural clay rich in kaolin as a control material. The tests performed in the current study to identify the mechanical suitability included compaction tests, unconfined compression tests, hydraulic conductivity and swelling tests. In addition, column adsorption tests were conducted to determine the adsorption capacity of the all specimens.

2. Materials

The sepiolite, zeolite and a kaolin-rich clay (which is referred to as Eskisehir clay from hereafter) were used in the current study. The sepiolite and zeolite materials were obtained from the Eskisehir–Sivrihisar and Balikesir–Gordes regions in Turkey, respectively. Both sepiolite and zeolite were crushed and sieved through U.S. No. 200 (75 μm) sieve. The physical and chemical properties of the materials are summarized in Tables 1 and 2, respectively. The physical and chemical properties of the sepiolite and Eskisehir clay were determined by Guney et al. (2008). The sepiolite was classified as high plasticity clay (CH) according to the Unified Soil Classification System (USCS). The Eskisehir clay, the natural clayey soil, was classified as low plasticity clay (CL), with clay and silt contents of 76% and 24%, respectively. The zeolite was classified as low plasticity silt (ML) and had the highest cation exchange capacity (CEC) and Eskisehir clay had the lowest. Specific gravities of the materials ranged between 2.41 and 2.6. The shrinkage limits (%) of sepiolite and Eskisehir clay were determined as 39 and 25, respectively while it was zero for zeolite in accordance with ASTM D4943. In addition, pH and electrical conductivities of sepiolite, Eskisehir clay and zeolite were determined. The natural pHs of the materials varied from 7.2 (Eskisehir Clay) to 8.30 (Zeolite). The electrical conductivities of the sepiolite, Eskisehir clay and zeolite were 0.3 (mS/cm), 0.15 (mS/cm), and 0.12 (mS/cm), respectively.

Table 2
Chemical composition of the soils used in the current study.

Materials	Chemical constituent (%)					
	pH	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Sepiolite	8.14	52.5	–	–	22.8	24.6
Eskisehir clay	7.18	61	29.4	1.3	1.8	2
Zeolite	8.30	81.1	12.5	–	2.7	–

Note: chemical compositions are determined by weight (%).

In the current study, $CuCl_2$, $ZnCl_2$, and $PbCl_2$ salt solutions were used to evaluate the adsorption properties of sepiolite and zeolite materials along with the control material, Eskisehir clay. The concentrations of $CuCl_2$, $ZnCl_2$, $PbCl_2$ were prepared at 200 mg/L, 200 mg/L, and 1000 mg/L respectively. These concentrations are acceptable for municipal solid waste landfills and mine waste facilities (Jo et al., 2001). These three solutions were chosen since they are common in municipal solid waste landfill leachates (Pandian et al., 1996). Cu is very soluble in water and high concentrations of Cu and Zn can cause significant health problems (Jo et al., 2001; Jegadeesan et al., 2008; Svilovic et al., 2009). Pb is mostly found in industrial landfill waste and can cause delays in mental or physical development in children, and can initiate kidney and high blood pressure in adults (Dwivedi et al., 2011).

3. Methods

3.1. Scanning electron microscopy (SEM) analysis

Scanning electron microscopy (SEM) analyses were conducted on sepiolite, zeolite and Eskisehir clay soil to observe the microstructure of these soil materials. The specimens were prepared with the critical drying technique, as outlined by Bennett et al. (1977). The specimens were initially treated with acetone, and a critical point drying apparatus was utilized to replace the acetone with CO_2. The specimens were held on an aluminum sample holder with adhesive tape. Later, they were coated with gold to minimize any charge buildup (Cetin et al., 2010). Microstructure and chemical composition of the samples were examined under a LEO 440 Model SEM using the energy dispersive X-ray (EDX) technique. The chemical compositions of all three materials are listed in Table 2. The SEM images of the sepiolite (reported by the Macaulay Institute, United Kingdom), the zeolite and Eskisehir clay are shown in Fig. 1. Fig. 1a clearly shows the fibrous nature of the sepiolite. Because of this structure, the specific surface area of sepiolite is approximately 6 times higher than Eskisehir clay. The porous structure of the zeolite, evident in Fig. 1b, promotes the entrapment of heavy metals in the pores by the ion-exchange process (Elsayed-Ali et al., 2011).

Table 1
Properties of soils used in the study.

Materials	Clay (%)	LL (%)	PI (%)	G_s	CEC (meq/100 g)	SSA (m^2/g)	Activity	USCS
Sepiolite	69	132	47	2.5	30–50	95	0.67	CH
Eskisehir Clay	76	50	21	2.6	5	15	0.3	CL
Zeolite	–	NP	NP	2.41	165	31	–	ML

Note: LL: liquid limit, PI: plasticity index, G_s: specific gravity, CEC: cation exchange capacity, SSA: specific surface area, NP: non-plastic, UCSC: unified soil classification system.