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Original Research Paper

The Strength Deformation and Microstructure Properties of Clay Contaminated by Landfill Leachate

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ABSTRACT

In order to research the corrosive state of landfill liner system, which affected by landfill leachate, and explore its strength and microstructure properties, contacting reaction between landfill leachate and compacted clay landfill liner system was simulated. Then, clay samples of different layers were investigated by unconfined compressive testing, shear testing and static nitrogen adsorption testing. The results showed that corrosion degree of clay samples caused by landfill leachate increased with the decrease of deepness of clay. And the maximum unconfined compressive strength (UCS) decreased obviously along with the shear strength. The UCS at 10cm was 53.1% that of layer at 50cm and the shear strength was 40.4~62.4% at 10cm that of 50cm. The static nitrogen adsorption testing showed that the shape of clay particle was bottleneck like, and with the decrease of the depth of clay, there was a decrease in the number of micropores whose size was no smaller than 6nm. And the number of pores which was between 2nm and 5nm increased. In addition, there also appeared micropore which was smaller than 2nm. And the average pore size was decreased from 5.083nm at 50cm to 3.768nm at 10cm.

INTRODUCTION

Landfill leachate is a kind of organic wastewater with high concentration, which contains plenty of organic matter, inorganic ions and ion-organic compounds. Thus, without suitable control emission, leachate can cause pollution of natural soil near the landfill and the underground water, which could threaten human health directly (Xue et al. 2011, Zhong et al. 2014).

There were a lot of high valent cations in leachate. When leachate permeated into liner system, the high valent cations exchanged ions with cations in clay (Ayininuola et al. 2009, Chik et al. 2011). And the ion exchange weakened the expansibility of clay, leading to the increase of clay layers' permeating coefficient. This exchange not only changed the dispersivity of leachate but also reduced the impermeable ability of system. The deformation characteristics and the strength of clay were changed, and the compacted clay landfill liner system was affected (Sivapullaiah et al. 2010, Xiong et al. 2014, Li et al. 2015).

Nowadays, researches on landfill are mainly about how to transform and send away the pollution, rather than change and use it. So, the liner system of chemical solution landfill is still at beginning. For this, the experiment was based on a series of studies performed. By performing and simulating the contact reaction between the leachate and the system, the experiment recovered that the strength deformation rules and the microstructure characteristics of the compacted clay liner system, under the action of chemical solution.

MATERIALS AND METHODS

Testing materials: Clay used in testing was taken from a construction site in Wuhan. The basic physical properties and the chemical composition of clay are given in Table 1 and Table 2. Before testing, clay was selected through a 2mm round hole screen after manual crush, and the large particles were abandoned. After that, the sample was put in a 105°C constant temperature drying oven until there was no extra moisture. Then, the treated sample was sealed and reserved for testing.

The landfill leachate needed in testing was taken from a refuse processing plant in Wuhan. The basic properties of the leachate are given in Table 3 and the microstructure of clay is shown in Fig 1. From the figure, it is obvious that there are many scattered relics on surface of the sample. And both the surface and the edge of clay were irregular.

Analytical methods: Firstly, clay sample was put into a hyaline cylinder as shown in Fig. 2. In order to keep the compaction degree of clay column at 1.65g/cm^3, clay with depth of 10cm was firstly put into the cylinder and then compacted. Secondly, another 10cm layer of clay whose depth was also 10cm, was put into and then compacted. This kind of circle would be repeated until the height of soil

Table 1: The basic physical properties of clay used in tests.

ρ_{dmax}/ g/cm^3	W_{opt}/%	W_L/%	W_p/%	I_p	Particle size distribution /%			
					>0.05mm	0.05~0.005mm	0.005~0.002mm	0.002mm
1.65	19	48.5	26.2	22.3	12	32	45	11

Table 2: The chemical compositions of clay used in tests (%).

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O
58.42	25.23	0.24	0.51	0.12	5.32	2.67

Table 3: The properties of landfill leachate.

Specific conductance (μS/cm)	Organic acid (mg/L)	pH	BOD_5 (mg/L)	COD_{cr} (mg/L)	Cd (mg/L)	Pb (mg/L)	As (mg/L)	Fe (mg/L)
1100	254000	7.5	17300	53212	0.15	1.73	0.4	64.8

column reached 50cm. After compaction, leachate was poured into cylinder until the depth of solution arrived at 30cm. Then the cylinder was sealed and reserved for testing.

Six months later, took out the soil column under leachate and equally divided it into 5 layers, according to the depth of column. Thus, the depth of every layer was 10cm and the first layer was nearest leachate. Some sample from each layer was taken and separately dried. Then it was broken into pieces passed through a 2mm round hole screen. When all above was done, these samples were investigated by strength deformation testing and microstructure testing. There were three parallel samples used in each testing.

The compaction degree and moisture content of clay samples were 1.65g/cm^3 and 0.19, respectively. According to soil test rule SL237-1999, the unconfined compressive testing and shear testing were performed to analyse the compressive strength and the shear strength properties of samples from each layer.

The low temperature N_2 adsorption experiment was performed to investigate the pore structure of clay. And the JW-BK static nitrogen adsorption instrument was applied for this experiment. In line with the standard BET method, the adsorption-desorption isotherm and the distribution state of pore volume, pore size of each layer were measured.

RESULTS AND DISCUSSION

Unconfined compressive strength: The confined compressive strength curves of samples with different depths are given in Fig. 3, from which it is clear that while the depth of clay layer decreased, the influence of leachate on unconfined compressive strength gradually strengthened. When the depth was 50cm, the maximum compressive strength reached the peak values of 122.7kPa. The deeper the clay layer was, the relatively smaller compressive strength was. When the depth was 10cm, the maximum unconfined compressive strength was also the smallest value of 65.18kPa.

The reason behind the phenomenon above can be explained as: When the sample was polluted by landfill leachate, the number of the organic-inorganic compounded colloid, the free oxide and soluble salt etc. decreased. Since those matters could connect clay particles, the adhesive property of particles became weaker. And with the increase of depth, there was an obvious decline when the axial stress reached the peak. Then, the destruction of samples gradually shifted from plastic failure to brittle one.

In addition, there was a sudden jump of the maximum unconfined compressive strength when the depth was between 30cm to 40cm. The reason behind it was that the leachate contaminated the upper layer, the particle size became smaller, thus making the skeleton structure of clay looser. Then, some of the subtle particles pass through the pore and permeate down with leachate. However, the pressure pressed on soil column increased with the depth, also did the compaction degree, thus making that the subtle particles cannot continuously permeate with leachate.

When the depth was between 30cm and 40cm, the deposit appeared. While the amount of the deposit reached to some extent, it could stop the permeating and making the sudden jump, which is caused by the contamination of leachate making the maximum unconfined compressive strength lesser.

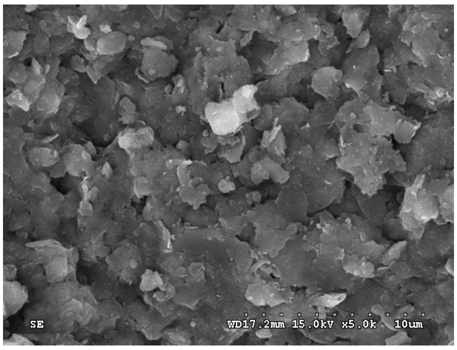


Fig. 1: The microstructure of clay.

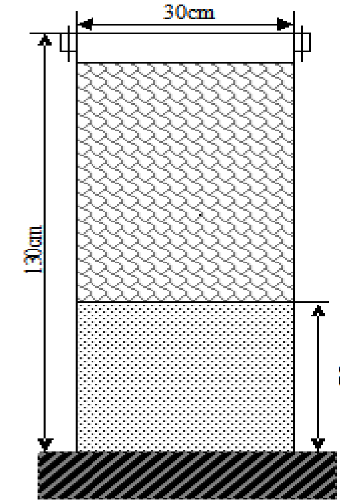


Fig. 2: The schematic diagram of experimental model.

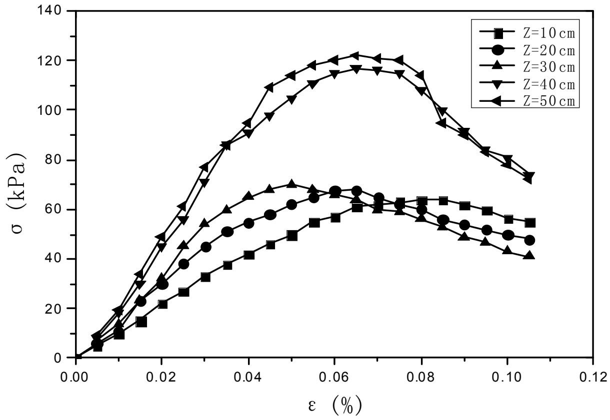


Fig. 3: The confined compressive strength curves of samples with different depth.

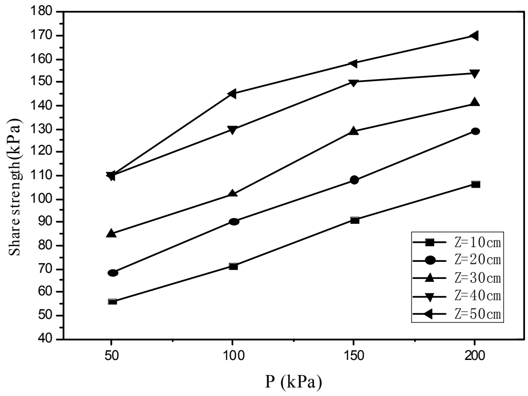


Fig. 4: The curve of shearing strength as clay contaminated by landfill leachate.

Daniel (Zhu et al. 2008) considered that the minimum unconfined compressive strength of compacted clay landfill liner should be 200kPa. However, all of the maximum unconfined compressive strength given in Fig. 3 was smaller than 200kPa. Thus, there was an apparent decline in the compressive property when clay was polluted by leachate for a long period, which meant that such clay was not suitable for landfill liner.

Shear strength: The shear strength of the sample is given in Fig. 4 and the shear strength index is given in Table 4. From the table, it can be seen that under the same vertical pressure, the shear strength of samples increased with the increase of the depth of layer. But, because that layer at 10cm had direct physical contact with the landfill leachate, the leachate had great influence on this layer. Thus, this layer had the lowest shear strength. And when the depth of layer increased, it took more time for leachate to permeate into clay which meant the permeating amount became smaller. Besides, when the upper layer of clay column was contaminated, along with the contaminating ability, the acid-base concentration and the concentration of the heavy mental ions of leachate also declined a bit. Hence, the contamination degree of lower layer was alleviated. So, the shear strength of layer at 50cm was 60.4%~104.2% that of layer at 10cm.

From Table 4, it also shown that at the same layer, clay was evenly polluted by the leachate. And the surface of clay particles became smoother, which affected the interaction between the particles. Since the interaction was caused by the vertical constrained force and the horizontal constrained, when the interaction was affected, the internal friction angle of clay became smaller and the pore size of the polluted clay became larger.

The distance between particles also became shorter, thus, the electrostatic attraction became weaker, so did the original connection between clay particles. And since the inter-

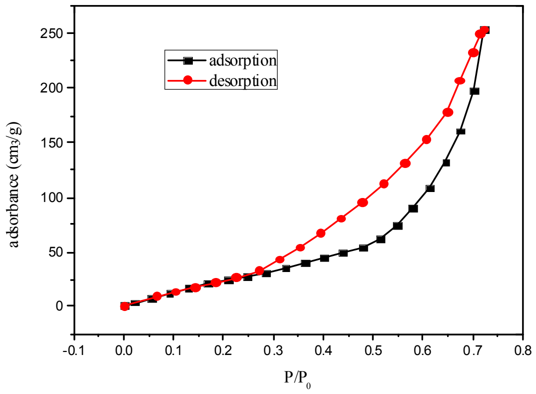


Fig. 5: Sorption isotherm of 30cm depth sample.

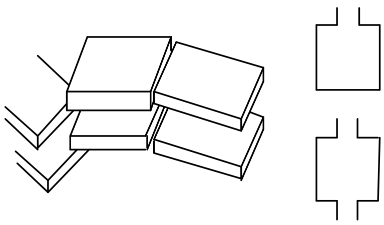


Fig. 6: The bottle model (one and both ends of the hole).

nal friction angle was affected by the sliding and interlocking effect between particles, and the physico-chemical interaction on the surface of particles, the cohesive force of sample was decided by the mutual electrostatic force, the Van der war force and the connection between the charged particles (Griffiths et al. 1989). Hence, the cohesive force and the internal friction angle of clay particles contaminated by the leachate became smaller. And with the increase of the depth of layer, the infiltration degree of the leachate gradually decreased, so did the contamination degree. Because that the cohesive force and the internal friction angle increased gradually, the shear strength was also gradually strengthened.

Pore structure and pore size distributions: The pore structure of clay sample was investigated by N_2 adsorption-desorption experiment. Because that the sorption isotherm curves of each layer were similar, sorption isotherm curve of layer at 30cm was taken as an example to explain.

The isotherm of layer at 30cm is shown in Fig. 5. According to the IUPAC classification method, this isotherm belonged to the IV kind. When the relative pressure was smaller than 0.25, the adsorption amount was relatively low, and the curve was a bit of curving. When the relative pressure kept increasing, the isotherm ascended rapidly. And the adsorption branch separated from the desorption branch.

Table 4: The curve of shearing strength as clay contaminated by landfill leachate.

Soil depth (cm)	10	20	30	40	50
c (kPa)	42	67.5	71	99	101.6
φ (°)	15.78	16.6	16.6	20.6	21.7

Table 5: The average pore size in different depth samples.

Soil depth (cm)	10	20	30	40	50
Average pore size (nm)	3.768	4.066	4.834	4.930	5.083

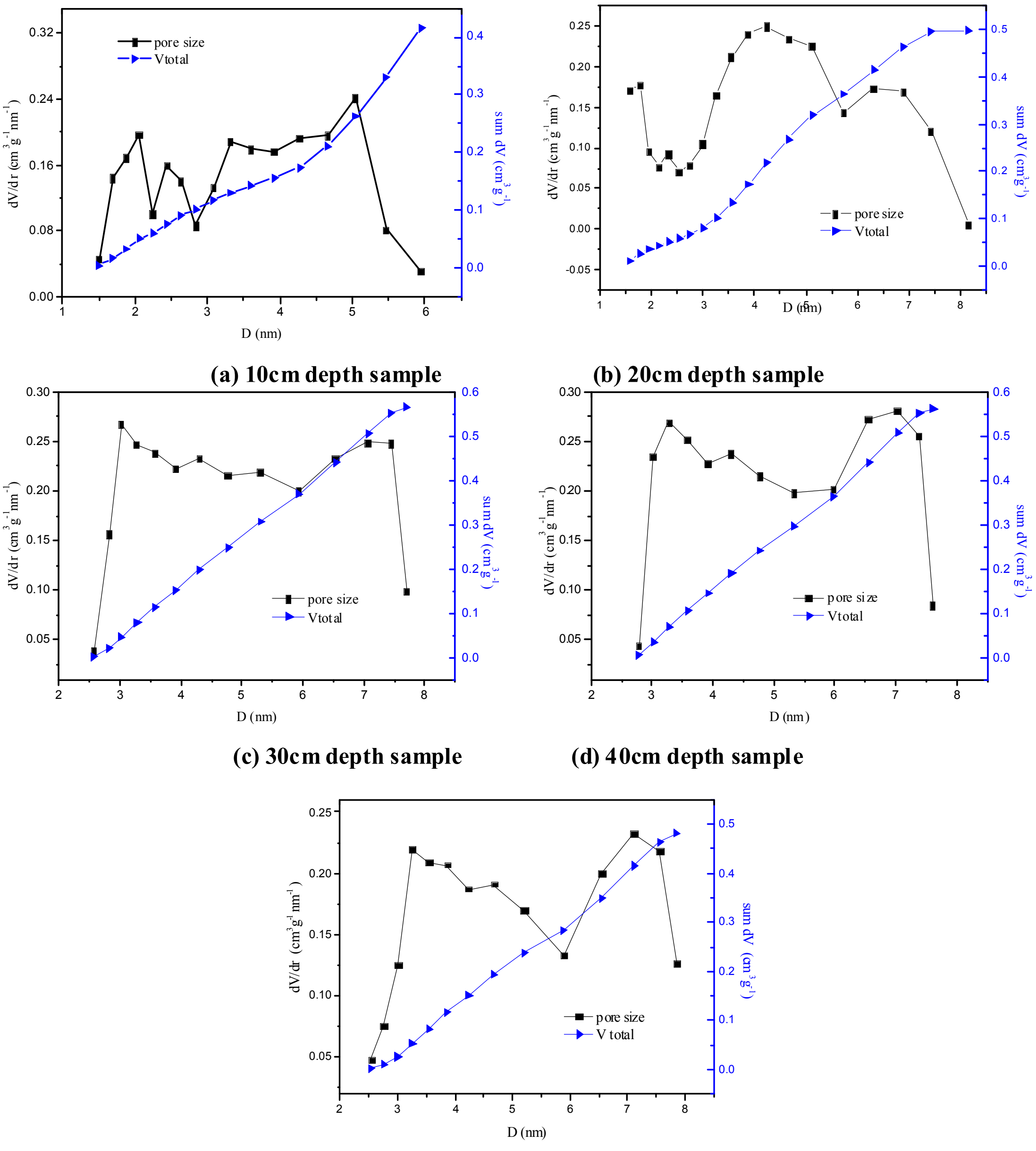
Thus, the hysteretic curve formed, meanwhile, because of the capillary condensation happened in the mesopores, the adsorption also increased rapidly. And when the relative pressure approached 0.75, the adsorption branch met with the desorption branch, but still at the unsaturated adsorption state. Thus, the curve was still rising and the adsorption mainly happened in macropores.

According to the IUPAC classification method, the hysteretic curve formed above belonged to H_2 kind. Because that the different shapes of curves stand for the difference of pore structure, which means the shape of sample pore structure is similar to the bottle-neck as the structure in Fig. 6 (Lu et al. 2014).

Under the action of capillary condensation, happened during the adsorption, the N_2 molecules condensed and filled in the pore canal at low pressure. And during the adsorption, the capillary condensation started at the liquid level of circular sorption film on the pore wall. While desorption began at the spherical meniscus of the pore. Thus, the contacting area of pore in desorption was smaller than that of the circular adsorption film, which caused the hysteretic phenomenon and the hysteretic curve appeared.

According to the IUPAC classification method, this hysteretic curve belonged to the III kind by pore size. When the pore is larger than 50nm, it is called macropore, when the size is between 2nm and 50nm, it is called mesopore, and the smaller than 2nm is micropore (Shao et al. 2015). By analysing the adsorption-desorption isotherm of nitrogen, and the relationship between the pressure and the adsorption amount, the pore volume, the pore size could be measured. The curve of the relationship was drawn as Fig. 7.

The average pore size of clay from each layer is given in Table 5. It is shown that the range of pore size of each layer was between 1.5mm and 8.0mm, it was micropore and mesopore. The pore size distribution curve of layer at 50cm had two apparently wide peaks. The peak appeared at 3.0mm and 7.0mm. And as for layer at 50cm, the pore size distribu-



(a) 10cm depth sample (b) 20cm depth sample

(c) 30cm depth sample (d) 40cm depth sample

(e) 50cm depth sample

Fig. 7: The curve of pore size and pore volume in different depth samples.

tion was even and the average size was 5.07nm.

From layer at 50cm to 10cm, as the depth of layer declining, the characteristic-the two peaks, became unobvious. But the pore size distribution between 3nm to 7nm was more even. The average pore size also became smaller.

When layer declined to 20cm, the micropores appeared. Meanwhile, the proportion of mesopores, whose size ranged from 2nm to 6nm, gradually increased while the number of macropores, whose size was larger than 6nm, rapidly decreased. And when layer was at 10cm, the average pore size reached the smallest numerical value. The mesopore, ranging from 2nm to 5nm, also distributed evenly. There was no mesopore larger than 6nm when layer was at 10cm.

Since both the surface and the inside of pore were corroded by heavy mental ions and acid-base solution, the perforation phenomenon happened in plenty of clay particles and produced the colloidal matter. Thus, the original skeleton structure between particles was destroyed. Moreover, since those particles had charges on their surface, under the action of the attraction between charges and the Van der Waals' force between particles, the particles would be rearranged. And new porosity was produced, because the original colloidal matter filled in pore and packed around the particles.

From the shape of that new pore, we could know that this new pore was smaller than the original ones. Hence, with the decline of the depth of layers, the average pore size also declined.

CONCLUSIONS

In order to study the strength deformation properties and the microstructure characteristic of the landfill liner with different depths, the model of landfill liner was made. The characteristics of landfill liner with different depths were investigated by unconfined compressive strength testing, the direct shear strength testing and the low temperature N_2 adsorption experiment. Based on this study, the following conclusions can be drawn:

The landfill leachate has great influence on the physical strength of clay. With the decline of the depth of clay layer, the contamination degree caused by the leachate gradually increased. The unconfined compressive strength also gradually declined. Moreover, for layer at 10cm, the maximum unconfined compressive strength was 65.18kPa, only the 53.1%that of layer at 50cm. As for the shear strength, the shear strength at 10cm ranged from 40.9% to 62.4% when compared with the strength of layer at 50cm. And when layer was at 10cm, the cohesive force was 42kPa, and the smallest internal friction angle was 15.78°.

The shape of clay particle was bottleneck like. When the contamination degree increased, the number of mesopores whose pore size was larger than 6nm was decreased, and the number of pore whose size ranged from 2nm to 5nm increased. Moreover, the micropores which were smaller than 2nm also appeared and the average pore size declined from 5.083nm at layer of 50cm to 3.768nm at the layer 10cm.

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