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Analysis of the Properties and Anti-Seepage Mechanism of PBFC Slurry in Landfill

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Abstract: As the landfill leachate has strong pollution on the underground water, surface water and soil. This paper develops the formula of impervious slurry with low permeability, good durability, strong adsorption and retardant based on the bentonite which is modified by polyvinyl alcohol. Through the simulation experiment, the optimum formula of polyvinyl alcohol is 0.2%. Its osmotic coefficient for 28 days is 0.53×10^{-8}~1.86×10^{-8} cm/s and compressive strength is 0.5~1.5 MPa as well. This paper study on the retardant rule of the consolidation of slurry against the pollution in the leachate by self-made percolation instrument. The experiment shows that the retardant rate of the consolidation against inorganic pollutants and organic pollutants is over 85% and the retardant rate against heavy metal ion such as Hg and Pb is above 99%. The slurry has the characteristics of low permeability, high retardant against pollution, good durability and plasticity, no chemical additives, no pollution, wide source of raw materials and good economy which determine it can be used to new landfill or existing landfill, building foundation pit and water conservancy project.

Keywords: Waste landfill, anti-seepage slurry, seepage resistance, adsorption property, corrosion resistance, durability, mechanical property.

1 Introduction

With the development of society and economy, people's quality of life has been greatly improved. However, the complex and intractable domestic garbage has increased dramatically, which has caused serious damage to the ecological environment. The highly polluted leachate will be produced in the process of garbage collection and disposal. This landfill leachate has complex components and high content of organic matter, which is likely to cause air pollution and make it difficult for all kinds of organisms to survive. At the same time, if leachate cannot be effectively controlled, it will cause irreversible pollution to soil, groundwater and surface water resources [Yao, Mao, Feng et al. (2010)]. Therefore, the effective control and treatment of landfill leachate is an important problem to be solved urgently in the process of modern city development. In the process of

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municipal waste treatment, the treatment method of direct garbage sanitary landfill is the most widely used for its advantages of simple, convenient and low cost. But the leachate produced during the landfill will cause serious impair to the surrounding environment. Therefore, it is very important to established a safe and effective seepage control system in the construction of landfill. It has been proved that the vertical seepage control system with appropriate slurry can effectively prevent the diffusing of the leachate to the surrounding soil [Guo (2010)].

At present, researchers from all over the world have done a lot of research on anti-seepage slurry. Li et al. [Shu-Zhan, Shi and Xie (2008)] proposed to compounded the dewatering sludge from municipal sewage treatment plant and kaolin and add soil solidifying enzyme to make the impervious material in the landfill. The results showed that the vertical permeability coefficient of the landfill soil after adding the curing enzyme decreased by 36%; Chen [Chen (2010)] used bentonite, zeolite and red mud as anti-seepage materials to design different structures of seepage proof lining and carry out soil column test. It is found that these three materials cannot meet the requirements of the lining of the landfill when they are used separately as lining; Wang [Wang (2011)] put forward the single layer composite impervious structure using HDPE membrane plus bentonite pad (GCL) as the bottom impervious material, and realized the automatic repair function of the impervious material by using the swelling property of bentonite in water; Chen et al. [Chen and Lei (2013)] proposed shale modified clay as landfill liner. It is found that when the content of crushed shale is within 10%, the permeability coefficient of smashed shale modified clay can reach 10^{-7} cm/s, but it is not strong enough to adsorb organic pollutants; He et al. [Jun and Wang (2013)] found that the addition of bentonite in clay will affect the area and length of the crevice in the dry and wet cycle. The study on the properties of compacted clay after bentonite modification should pay more attention to the effect of the number of dry and wet cycles on the crack; Yang et al. [Yang, Gong, Wen et al. (2013)] determined the permeability and fouling resistance of gangue by infiltration test, adsorption test and leaching test, and found that adding fly ash can improve the adsorption performance of coal gangue impervious material; A new polyacrylamide modified bentonite anti-seepage material was prepared by Liu et al. [Xuegui, Yuechong, Hong et al. (2013)]. The natural sodium bentonite was used as raw material and the modified polyacrylamide was used to directly intercalate the bentonite. The removal of heavy metal ions is good; Sun [Sun (2014)] studies the mechanical properties of the modified clay by determining the liquid plastic limit and the maximum dry density value of the clay mixed with fly ash. So as to solve the problems of cracking, opening and disintegration of the anti-seepage layer of the landfill; On the basis of the study of the blocking mechanism, Jing [Jing (2014)] selected the pulverized clay, sodium bentonite, cement and fly ash to study the anti-seepage slurry. Dong et al. [Dong, Lu, Li et al. (2015)] proposed the use of sludge ash modified clay as a landfill liner. It was found that the shear strength of clay decreased significantly after corrosion of landfill leachate, and the shear strength of modified clay increased with the addition of sludge ash, and cohesion and internal friction angle increased with the increase of sludge ash content; Zhu et al. [Wei, Hao-Qing, Wang et al. (2016)] found that adding 10% $CaCl_2$ solution to sand-clay mixtures can effectively improve the permeability of the material and reduce the porosity of the mixed soil material; Mohamedzein et al. [Mohamedzein Alghaithi, Alaghbari et al. (2016)] discusses the potential use of dune sand-bentonite mixtures as landfill liners, the permeability coefficient of sand dune bentonite decreases with the increase of bentonite content; Jacob et al. [Jacob and Soorya (2017)] proposed using clay-bentonite as material used in the construction of landfill liner, the quantity and transport depth of leachate analysis. This liner is effective in preventing percolation of leachate into the deeper, so as to prevent the soil and groundwater pollution; Rout et al. [Rout and Singh (2017)] examined the suitability of compacted bentonite-pond ash mixes as landfill liner material, it can reduce the swelling and shrinkage, preventing the formation of any cracks in the compacted liner material; Sobti et al. [Sobti and Singh (2017)] found that the addition of bentonite improved the adsorption capacity of sand and fly ash. The best ratio was 20% for sand-bentonite and coal ash-bentonite mixes.

According to the research data, the anti-seepage wall in landfill is usually made of clay-bentonite (SB), cement-bentonite (CB) and precast concrete [Gotvajn, Tisler and Zagorc-Koncan (2009)]. The material is added fly ash or slag to ensure the osmotic coefficient less than 10^{-7} cm/s and enough strength and durability [Mishra, Ohtsubo, Li et al. (2013)]. Therefore, the research of bentonite-fly ash-cement (BFC) impervious slurry is the main direction. The slurry select bentonite, cement and fly ash as the main material and chrome lignosulfonate (FCLS), high efficient naphthalene superplasticizer (NUF-5) and polycarboxylate superplasticizer (TOJ800-10A) as the water reducing agent. BFC slurry is divided into three types: N type, S type and Z type. N type slurry is clay-slurry based on large amount of clay, S type slurry is cement-slurry based on large amount of cement, Z type slurry is neutral slurry based on equal amount of cement, clay and fly ash. The impervious property of N type slurry is stronger among those slurry.

Raw bentonite can only effectively prevent the migration of low tension leachate [Nguyen, Lee and Choi (2011)]. It will flocculate and shrink under the action of high concentration organic leachate. This will result in the rapid decline of its ability to adsorb organic pollutant [Fleming (2011)]. It can use organic modifier to improve microstructure and particle surface properties of bentonite because of its interlayer structure and physical properties. It can effectively control pollution at the situation of low permeability by this way. This will greatly improve the efficiency of bentonite in the practical engineering. Therefore, it takes polyvinyl alcohol to modify bentonite to make impervious slurry (PBFC slurry) based on the clay-slurry (N type). The impervious property of PBFC slurry is better than other BFC slurry and the PBFC slurry has more broad application prospects.

2 Selection of raw materials and optimization of formula

Bentonite, fly ash, cement and polyvinyl alcohol are selected as the main addition materials for the impervious material of landfill site. that is, based on the preparation of clay based BFC slurry, polyvinyl alcohol is added to modify bentonite, and sodium carbonate and polycarboxylate superplasticizer are added. Modified bentonite-fly ash-cement anti-seepage slurry is prepared (simply called PBFC anti-seepage slurry). The composition and material selection of PBFC anti-seepage slurry are as follows: Bentonite: calcium bentonite after treatment of sodium, the content of montmorillonite is above 60%; Fly ash: ordinary second-quality fly ash produced by heat-engine plant; Cement: 42.5 grade ordinary portland cement; Polyvinyl alcohol: type 1788 (or type 2788); Polycarboxylate superplasticizer: type TOJ800-10A; Soda ash: anhydrous sodium carbonate.

The orthogonal test of 4 factors and 3 levels was adopted to optimize the slurry formula, and the orthogonal experimental factors and levels of slurry were determined through the contrast test [Dai and Yin (2011)]. Schedule of test scheme is shown in Table 1 and Table 2.

Table 1: Experimental factors and levels of PFCF anti-seepage slurry

levels	factors %			
	A (bentonite)	B (cement)	C (polyvinyl alcohol)	D (superplasticizer)
1	18	16	0.2	0.01
2	22	20	0.5	0.02
3	26	24	0.8	0.03

Note: additional amount of other admixtures: 18% fly ash, 0.5% soda ash.

Table 2: Proportioning scheme of slurry in orthogonal test

number	percentage of each factor (%)			
	A	B	C	D
1	18	16	0.2	0.01
2	18	20	0.8	0.02
3	18	24	0.5	0.03
4	22	16	0.5	0.02
5	22	20	0.2	0.03
6	22	24	0.8	0.01
7	26	16	0.8	0.03
8	26	20	0.5	0.01
9	26	24	0.2	0.02

Note: The percentage of parameters refers to the dry weight ratio of the material; Polyvinyl alcohol was added into bentonite slurry in the form of solution.

3 Analysis of anti-seepage performance

3.1 Determination of permeability coefficient of slurry

The permeability coefficient of the pulp is tested by N-55 variable head osmometer, and the calculation formula of permeability coefficient is as follows:

$$k_T = 2.3\frac{aL}{A(t_2 - t_1)}\lg\frac{H_2}{H_1} \tag{1}$$

Where a is the section area of the variable water head (cm^2); L is the seepage diameter, that is the height of the sample (cm); H_1, H_2 is the start water head and the end water head respectively for testing (cm); t_1, t_2 is the time to start the head and the time to end the head respectively (s).

3.2 Experimental methods and results

According to the requirement of each group, the amount of bentonite was obtained, then the polyvinyl alcohol solution was added to the sodium carbonate solution and then evenly stirred. The bentonite was modified by organic reaction in alkaline environment for 1~2 days. Cement and fly ash are added to the modified bentonite in turn, then add the right amount of water, stir it slightly, and add polycarboxylate superplasticizer into water to dissolve, then the solution is added to the slurry, and the pulp is stirred to uniform with the mixer evenly. The mixed slurry is poured into the test mold, and the slurry is treated with water after initial coagulation.

The permeability coefficient of slurry was measured by TST-55 variable head permeation instrument, which produced in Nanjing soil instrument factory. The tap water was used as the osmotic solution to measure the permeability coefficient of the slurry, because of the penetration of the slurry concretion body on the water was stronger than the pollutant solution [Broderick and Daniel (1990)]. The size of the test block is 50 mm (high)×80 mm (diameter). The results of the experiment are shown in Figure 1.

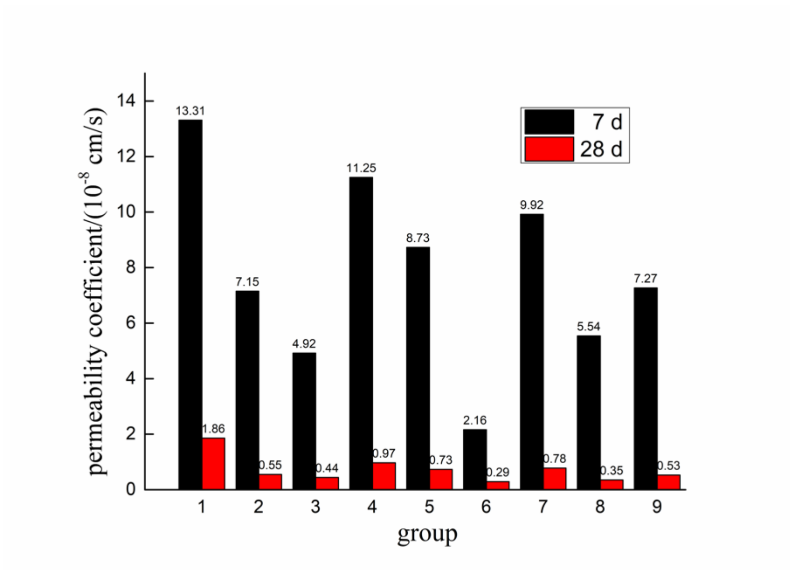
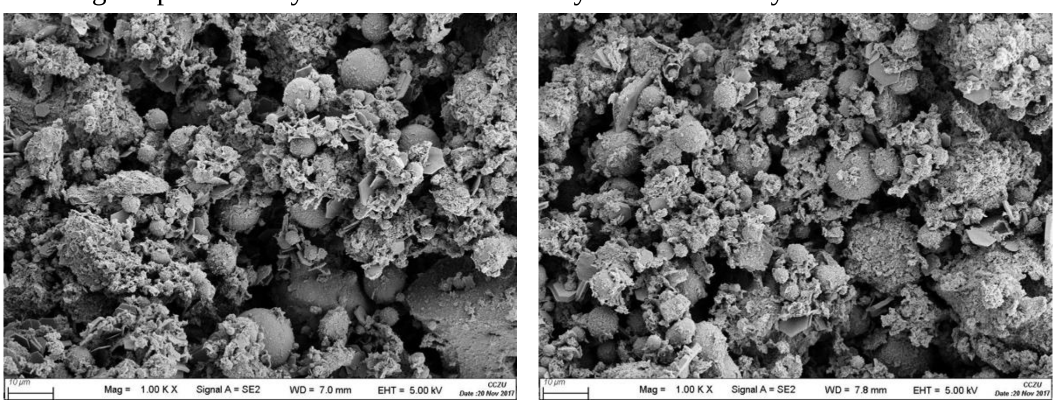


Figure 1: Variation of permeability coefficient with age

3.3 Analysis of comparison of permeability coefficient

As can be seen from Figure 1, the permeability coefficient of the slurry concretion body with longer curing period is obviously lower than that with shorter curing period. Its decrease range is 7~15 times, and the average decrease is 11 times. The longer the curing period, the higher degree of the cement hydration, and more compact of concretion body structure. While the freedom combined water in bentonite tends to be stable, and the porosity decreases with the increase of density and strength of cement hydration products. These have resulted in a marked change in the permeability of the consolidated body at different ages.

Large amounts of stable gel properties produced in the anti-seepage slurry, which was caused by the hydration reaction of cement [Luan, Pan and Wang (2010)]. A large number of hydration products such as calcium silicate hydrate (C_2S, C_3S), hydrated calcium aluminate and ettringite produced, it fills the void further. At the meantime, the bentonite with better dispersibility makes the hydration in the impermeable slurry more fully and evenly distributed, and the production rate of C_2S and C_3S has been increased because the sufficient contact surface and the sufficient contact space [Liu, Wang and Ding (2010)]. In addition, the hydration reaction of cement can produce a large amount of Ca $(OH)^2$, In addition, the hydration reaction of cement can produce a large amount of Ca $(OH)^2$, and the active cations such as Na^+ and K^+ can interact with Ca^{2+}. So that the secondary hydration reaction can be produced in the bentonite, and which makes the dispersion layer of the bentonite particles thinner. Meanwhile, the colloidal particles can be adsorbed between each other, resulting in a larger aggregate filled between the holes, as shown in Figure 2 (a), (b), thereby improving the compressive strength of the slurry concretion body, and reducing the permeability coefficient of the slurry concretion body.



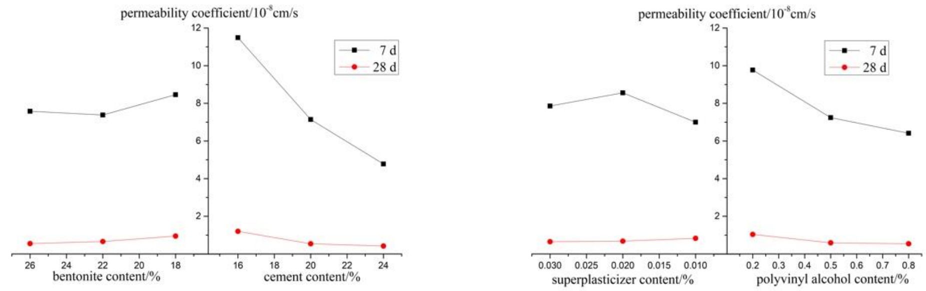
(a) SEM 1000 times image for 7 days curing slurry

(b)SEM 1000 times image for 28 days curing slurry

Figure 2: SEM image of slurry in different curing period

3.4 Analysis of the influence of various factors on the permeability coefficient

The results of the orthogonal test were treated by the method of extreme value, the effects of various factors on the permeability coefficient of the concretion body were analyzed, as shown in Figure 3 (a), (b).



(a) effect of cement and bentonite on permeability coefficient

(b) effect of superplasticizer and polyvinyl alcohol on permeability coefficient

Figure 3: The influence of various factors on the permeability coefficient

It can be seen from Figure 3, with the increase of cement content, bentonite content and polyvinyl alcohol content, the permeability coefficient of the concretion body after 7 days and after 28 days decreases. The decreasing trend slows with the increase of the content of the component. The influence degree of various factors on the permeability coefficient of the concretion body after 28 days from large to small is as follows: cement, polyvinyl alcohol, bentonite and superplasticizer. The effect of polyvinyl alcohol on permeability coefficient is higher than that of bentonite. the permeability characteristics of modified bentonite are better than natural bentonite. The best proportioning combinations (percentage of mass) were: 18% to 24% cement, 18% to 26% bentonite, 0.2% to 0.8% polyvinyl alcohol, 0.01% to 0.03% superplasticizer. The optimal combination is 20% cement, 22% bentonite, 0.2% polyvinyl alcohol, 0.03% superplasticizer and 24% cement, 26% bentonite, 0.5% polyvinyl alcohol, 0.02% superplasticizer. Although the permeability coefficient is small when polyvinyl alcohol content is 0.5%, but at this time, when the slurry is stirring, it is easy to generate bubbles, which leads to the decrease of permeability. Therefore, the amount of polyvinyl alcohol should not exceed 0.5%. At the same time, the difference of the permeability coefficient is very small when the addition of polyvinyl alcohol is 0.5% and the addition amount of polyvinyl alcohol is 0.2%. Therefore, when polyvinyl alcohol is added to 0.2%, it is the best combination, and the optimized combination obtained from the orthogonal array is fifth groups.

3.5 Analysis of the change trend of permeability coefficient with time

The change of permeability coefficient of the slurry concretion body with time is shown in Figure 4. This diagram is the change of the permeability coefficient with time within 28 days about three groups of the slurry concretion body that are representative in the orthogonal test table. The results show that the permeability coefficient of slurry solids increases first and then decreases with time. From the later test, it is known that after 18 days, the permeability coefficient is relatively small, and the different ratios are close to a certain constant. After 28 days' maintenance, cement hydration process is basically completed [Kong, Zichen and Zhang (2017)]. The density of the slurry concretion body is large and the permeability coefficient is small. As time goes on, the seepage channel of the solid body is formed, resulting in an increase of permeability coefficient. At the same time, the modified bentonite has high adsorption and high cohesion. The further hydration reaction is produced between fine particles carried by adsorption seepage and cement, fly ash, etc. within the seepage channel. This causes the channel to be blocked, and the permeability coefficient is further reduced and gradually close to a small constant.

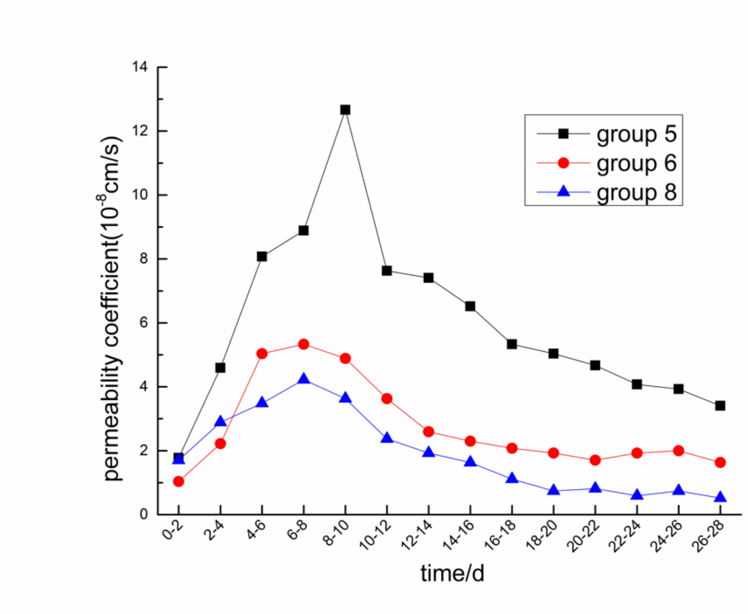


Figure 4: The variation trend of permeability coefficient with the penetration time

4 Analysis of the performance of adsorption block

4.1 Experimental device and experimental method

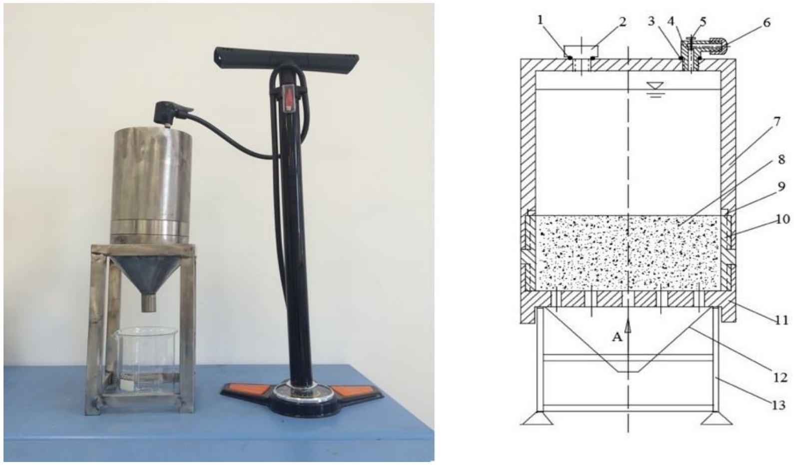


Figure 5: Structure composition of self-made adsorption block test instrument

Note: 1, 3, 9-sealing ring; 2-nut; 4-air inlet valve; 5-regulating rod; 6-valve block; 7-liquid storage chamber; 8-pulp material; 10-sample chamber; 11-base; 12-cone; 13-ring bracket

The self-made diafiltration apparatus (Figure 5) was used to test the adsorption retardation of PBFC slurry, the diafiltration apparatus is made up of sealing ring, nut, intake valve, adjusting rod, valve plugging, liquid storage chamber, slurry material, stone body, sample chamber, base, cone-shaped cylinder, annular support and so on. The lower part of the storage tank is connected with the sample room. The top cover of the storage room is opened with the intake hole and the inlet hole respectively, and the slurry stone body is loaded into the sample room, garbage landfill leachate (or artificial heavy metal solution, phthalate solution) into the liquid storage chamber. The leachate is pressurized by the compressed air through the intake valve, and the atomic absorption spectrophotometer, flame atomic absorption spectrophotometer, high performance liquid chromatograph and other instruments (see Figure 6, Figure 7 and Figure 8) were used to test the composition of samples after leachate filtration, and their adsorption blocking properties could be analyzed.

Figure 6: Atomic fluorescence photometer

Figure 7: Flame atomic absorption spectrophotometer

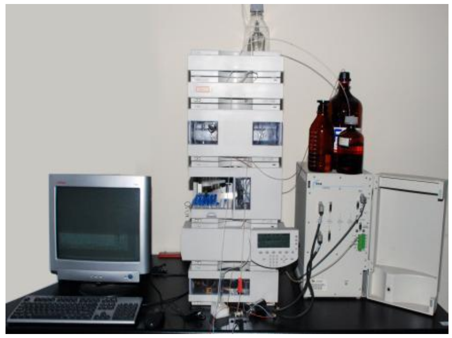


Figure 8: High performance liquid chromatography

The fifth groups of orthogonal test were selected, and the formula was (according to the preparation of 1000 mL slurry): 200 g cement, 220 g bentonite, 180 g fly ash, 2 g polyvinyl alcohol, 0.3 g superplasticizer, 5 g soda ash, 750 mL water. The curing time was 28 days, the penetration time was 30 days, the water pressure was 12.5 KPa. The diameter of the test block was 100 mm, the thickness was 30 mm. The filtrate from Changzhou landfill, artificial phthalate solution and heavy metal ion solution infiltration were adsorption block test respectively. The composition and content was shown in Table 3.

Table 3: Composition and index of pollutants

pollutant name	composition and index (mg/L)				
landfill leachate	NH_4-N	TP	SS	COD_{cr}	BOD_5
	2007.9	17.946	2170	23333.3	8700
phthalate solution	dimethyl phthalate			dioctyl phthalate	
	6.5			6.5	
heavy metal ion solution	Hg			Pb	
	2			30	

4.2 Experimental result

According to the solubility analysis of the contaminant solution after the block test, the block rate and unit block rate of the components in the solution were calculated. The result is shown in Figure 9.

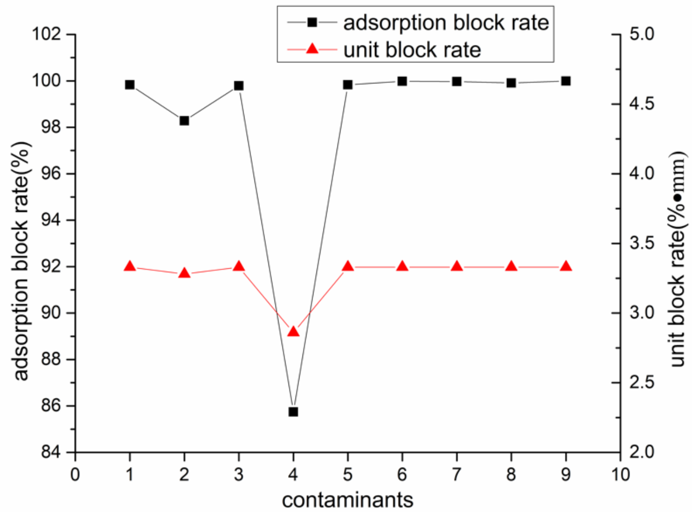


Figure 9: Retardation rate and unit block rate of slurry to pollutants

For the block test of landfill leachate, the exudated solution is pale yellow or white. The solution is transparent, and has no pungent odor of the leachate from the original landfill site. After testing the components such as CODcr, NH_4-N, lead and mercury in the leachate, its content can meet the requirements of the index. It is known that the contaminant components of the leachate are effectively blocked by the adsorption block of the consolidated body test block.

The concretion body modified by polyvinyl alcohol has high adsorption properties of block on the components of phthalate esters in solution. Especially for the dioctyl phthalate, which is lower than the detection limit of the instrument, the calculated blocking rate is above 99.9%, and the blocking rate of unit length reaches 37%, which meets the index requirement of China's sewage discharge (GB8978-1996).

For the heavy metal solutions, the slurry concretion body has high adsorption block performance for mercury (Hg). Overall, the adsorption retardation rate of modified slurry concretion body to all components in heavy metal solution reaches 99.98% and above. The retardation rate per unit length is over 37%, which completely meets the requirements of China's heavy metal ion discharge index (GB8978-1996).

Therefore, the leachate filtered by PBFC impervious slurry material, whether organic or heavy metal has met the discharge requirements, and even has reached the first level discharge requirement [Renou, Givaudan, Poulain et al. (2008)], which proves the superiority of this slurry.

4.3 Analysis of adsorption block mechanism

Contaminants in leachate from landfills can be prevented by clay based the slurry concretion body, because of the percolation sedimentation by concretion body and the adsorption retention by bentonite and fly ash.

Because of the bentonite has hydration swelling, dispersivity, ion exchange capacity and other characteristics [Vryzas, Kelessidis, Nalbantian et al. (2017)]. The volume of the bentonite can be expanded to 10-30 times the original after bentonite hydration, and the stable gel can be formed [Tahir and Rauf (2006)]. The permeability coefficient of concretion body can be less than 10^{-9} cm/s. The ion exchange of dispersed clay, particle coalescence and coagulation reactions were taken place due to the massive calcium ion produced by hydration reaction of cement. So the effect of water retention was mainly due to various hydration reactions or other reactions, and Figure 10 shows the reaction process.

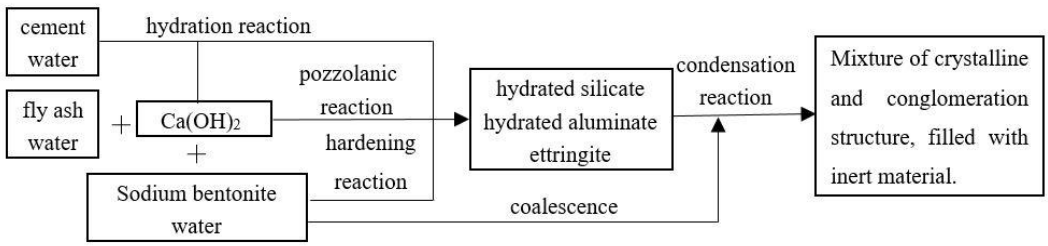


Figure 10: Schematic diagram of hardening process of cement-bentonite-silt slurry

The clay-based slurry concretion body has low permeability coefficient, the gap inside it is small and the connection is poor. The hydration reaction is promoted after the modification of the polyvinyl alcohol, and this property makes the slurry concretion body denser. The leachate suspended solids, solid particles and large molecules will remain deposited in the gap of the concretion body when the landfill leachate through the slurry concretion body. As the permeation proceeds, the permeability coefficient of concretion body was further lowered because of the particles trapped in the concretion body gradually block pores in the concretion body, and the smaller pores can hold smaller particles. This situation also blocked the runoff of contaminated liquid and formed the percolation sedimentation of concretion body.

For the adsorption retention, the physically adsorbed and chemically adsorbed will happen between leachate and concretion body. The structure and properties of bentonite have changed greatly after the modification of polyvinyl alcohol. The specific surface area of bentonite particles has been increased, and the cohesion of the particle surface has been improved [Thomas (2017)]. This change gives bentonite a huge interlayer space and a special adsorption property. The adsorption properties of bentonite were increased, and the further diffusion of pollutants has been prevented [Kurniawan, Lo, Chen et al. (2008)].

5 Analysis of corrosion resistance

5.1 Experimental scheme

The material in the vertical impervious wall will react with pollutant components under the erosion of various underground water and leachate if the material is unsuitable [Qin (2016)]. Thus, the durability of the impervious wall will directly affect the impermeability of the wall. The experiment of durability has been taken to determine the durability of the slurry concretion body [Singgih, Handayani and Setyawan (2017)].

The curing age of the slurry concretion body is 28 days under the condition of standard maintenance. The experiment takes the fifth formula in the former orthogonal experiment (20% cement, 22% bentonite, 18% fly ash, 0.2% polyvinyl alcohol, 0.5% Na_2CO_3, 0.03% superplasticizer, and the rest is water).

The erosion solution separately uses the leachate form the landfill, artificial phthalate solution and heavy metal ions solution and distilled water. The content of the first three pollutants in the solution is shown in Table 3. The specific method is as follows: drying the surface moisture of the slurry concretion body for 28 days, then placing in a beaker with erosion solution after being weighed and regularly taking out to determine the mass of the test block. The anti-erosion performance is valued by the changing mass of the block [Gunasekara, Bhuiyan, Law et al. (2017)].

5.2 Analysis of experimental results

The changes of the apparent properties of the slurry concretion body in different solutions are shown in Figure 11 (a), (b) and (c). Which can be observed in different solution soak process, the whole block does not appear phenomenon of destruction, holes and dispersion and erosion. The specimen surface is still showing a dense state but only a slight change in color in the process of leachate soak. The block strength does not change which is confirmed by the unconfined compressive strength test after soaking.

(a) initial state of test block (b) the immersion process of the test block

(c) the test block was soaked for 56 days

Figure 11: Appearance change of immersion test block

The changed mass of the slurry concretion body during process of soaking for 56 days are shown in Table 4. The mass changes of block (relative to the initial mass) with time are shown in Figure 12.

Table 4: Corrosion resistance of the slurry concretion body

time	erosive solution							
	Landfill leachate		Heavy metal solution		Phthalate solution		Distilled water	
	quality/g	Mass change/%	quality/g	Mass change/%	quality/g	Mass change/%	quality/g	Mass change/%
0	132.5	0	145.3	0	139.8	0	144.6	0
7	133.45	0.72	145.75	0.31	139.82	0.01	144.9	0.21
14	133.65	0.87	145.76	0.32	139.81	0.01	144.94	0.24
21	133.75	0.94	145.77	0.32	139.81	0.01	144.97	0.26
28	133.87	1.03	145.77	0.32	139.82	0.01	145.01	0.28
35	133.97	1.11	145.78	0.33	139.84	0.03	145.02	0.29
42	134.08	1.19	145.79	0.34	139.84	0.03	145.05	0.31
49	134.13	1.23	145.8	0.34	139.81	0.01	145.08	0.33

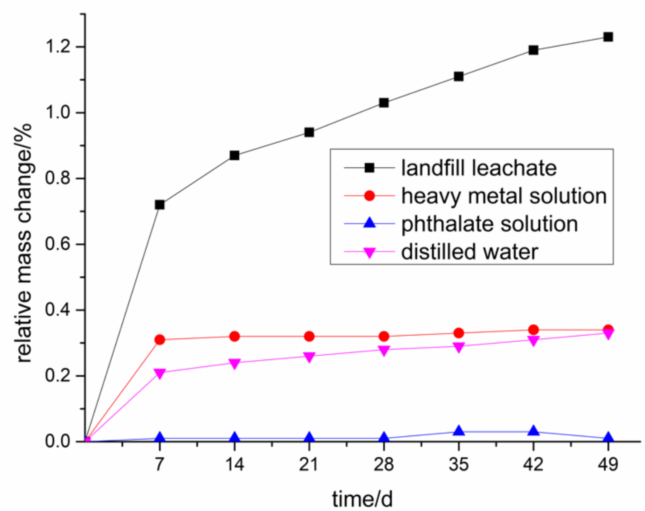


Figure 12: The change of the mass of the slurry concretion body with time

The overall trend curve shows that the slope of the curve is maximum removing the quality changes in the early stage under the action of leachate. It shows that relative quality changes and the erosion of leachate for the slurry concretion body is maximum under the action of leachate with complex components and properties. The slope of the curve is almost zero under the action of the heavy metal ion solution and phthalate solution. It shows that the slurry concretion body has strong anti-erosion performance against the heavy metal ion solution and phthalate solution.

The changed mass of blocks soaked in the leachate is the largest, followed by the heavy metal ion solution, distilled water and artificial organic solution (phthalate solution). The impervious material has a strong anti-erosion ability for organism after modified by polyvinyl alcohol. Meantime, the mass of blocks soaked in the phthalate solution does not change which illustrates that the blocks in the phthalate solution have little water absorbability or recurrence the hydration reaction. Otherwise, the mass of later blocks is unchanged expect the increasing mass in the first because of water sucking for the heavy metal ion solution and phthalate solution. It shows that modified impervious slurry has excellent anti-erosion performance and durability against heavy metal ion and organic pollution. The slurry concretion body of impervious slurry has strong anti-erosion performance both in leachate, heavy metal ion solution and organic solution. The change of mass is less than 1% and all testing blocks do not appear to erosion phenomenon and characteristics after soaking.

Experiments show that the modified slurry concretion body has excellent stability and anti-erosion properties in leachate, phthalate solution and heavy metal ion solution which fully meets the requirements of durability index of impervious wall.

5.3 Analysis of anti-erosion mechanism

The mass of blocks in the leachate continuously increases later except the initial mass growth. There are some actions in the blocks under the erosion of leachate which changes the space structure of the blocks. The pollution components in the leachate which is complex destroy the space structure of modified impervious slurry and lead to the large holes. Otherwise, the leachate is weakly alkaline as well as the blocks themselves [Reynier, Coudert, Blais et al. (2015)]. Those environmental factors provide $(OH)^-$ for heavy metal ions and the precipitates are formed which fill in the gap or adhere to the surface of particles. Finally, there is various acid ion (such as SO_4^{2-}, $(OH)^-$) which can react with the slurry concretion body of modified bentonite-cement impervious slurry. This makes bad associativity between cement and bentonite and swell inter the slurry concretion body [Wang, Deng, Ma et al. (2018)]. This results in the increase of internal pore and large amount of precipitation, particles and water filling in the gap which leads to the increase of the mass of blocks.

The mass of blocks in the heavy metal ion solution is almost unchanged later except the initial mass growth which shows that the blocks has stable structure and strong anti-erosion performance against heavy metal ion solution. The mass of blocks without modified trends to increase in the heavy metal ion solution. This is mainly because the heavy metal ion destroys the space structure of unmodified impervious slurry and the pore structure is formed which result in the precipitation of ion and the particles filling in, in which the mass of blocks increases [Wang, Cui, Xu et al. (2016)].

The changed mass of blocks is minimum and almost unchanged in the phthalate solution. The bentonite is modified by polyvinyl alcohol and the components of polyvinyl alcohol which will not destroy the structure of bentonite can coexist with bentonite. Meanwhile, the special formula of the slurry concretion body makes the reaction speed of hydration slower under organic environment, so the changed mass of blocks under organic solution erosion is not large.

The mass of blocks in the distilled water increases. This is because the slurry concretion body reabsorbs water and the moisture content increases after contacting with water as well as a weak hydration phenomenon. Those makes the mass of blocks increase and the changed mass larger than that in organic solution.

6 Analysis of mechanical properties

6.1 Test scheme and result

The permeability and mechanical properties of the anti-seepage wall of the landfill are complementary to each other. If any parameter cannot reach the index, the material cannot be put into use. Therefore, the experimental materials of mechanical properties are mainly composed of modified organic bentonite, ordinary portland cement and two grade fly ash, supplemented with anhydrous sodium carbonate and TOJ800-10A polycarboxylate superplasticizer.

The orthogonal test of 4 factors and 3 levels was still adopted to the orthogonal experiment, and the experimental formula is shown in Table 2. The unconfined compression test of the concretion body was carried out using the electronic universal test compressor. The loading rate was controlled at 0.5 mm/min. and the size of the unconfined compression test specimen is 40 mm (height)×70 mm (diameter). The results of the test are shown in Figure 13.

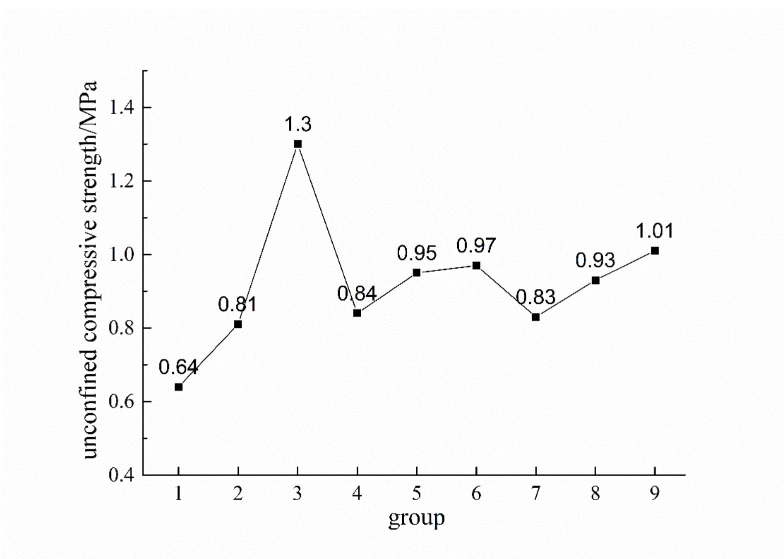


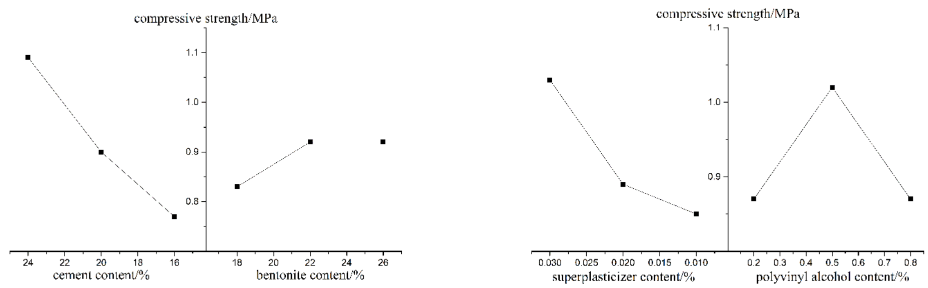
Figure 13: Variation of unconfined compressive strength with the ratio

6.2 Influence of various factors on unconfined compressive strength

The results of the orthogonal test were treated by the method of extreme value, the effects of various factors on the unconfined compressive strength of the concretion body of after

7 days and after 28 days were analyzed, as shown in Figure 14 (a), (b).

It can be seen from the analysis of Figure 14 that the influence of each factor on the compressive strength of the concretion body is different. The cement content has the greatest effect on the unconfined compressive strength of the test piece, and the next is superplasticizer, polyvinyl alcohol and bentonite.



(a) effect of cement and bentonite on the test block strength

(b) effect of superplasticizer and polyvinyl alcohol on the test block strength

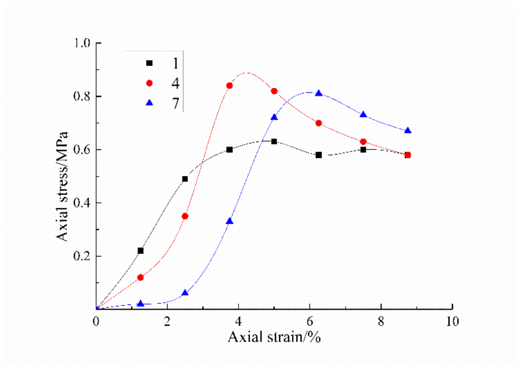
Figure 14: The influence of various factors on the compressive strength

The maximum unconfined compressive strength of the test piece was increased from 0.77 MPa to 1.09 MPa with the increase of the amount of cement, and the magnitude of the promotion is greater than the other three factors. The main reason is that the cement is the main skeleton in the concretion body. The concretion body structure can be more compact and complete when the increase in cement content, so the compressive strength of the concretion body was improved [Marar and Eren (2011)]. The compressive strength has also increased with the increase of superplasticizer. Because of the water-cement ratio was reduced with the increase of superplasticizer, and the spatial structure of the concretion body has been improved [Yu, Hao, Jiang et al. (2011)]. The major impact of the polyvinyl alcohol on the concretion body is that the polyvinyl alcohol improves the surface adhesion of the bentonite particles, and the adsorption performance has been improved. But the polyvinyl alcohol has little effect on the strength of the concretion body. Therefore, its influence on the strength is similar to that of bentonite.

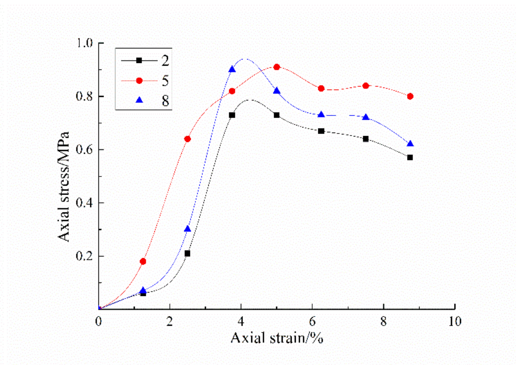
6.3 Unconfined stress and deformation characteristics of concretion body

For the vertical cut-off wall in landfill, although it does not need to bear large vertical loads, but in the role of landfill under the gravity, the wall will occur large horizontal displacement, which requires vertical anti-seepage wall and the surrounding soil with deformation modulus quite close, in order to achieve the cutoff wall deformation and soil the surrounding deformation coordination. However, the elastic modulus of the commonly used concrete impervious wall is generally (2~3)×10^4 MPa, when the foundation is subjected to the compression deformation of the upper load, the top of the concrete impervious wall will bear much more load than the upper soil column. The two sides of the wall will also suffer great friction. It will cause the wall stress to be too large in the normal use of the garbage yard, or even exceed the design strength of the concrete.

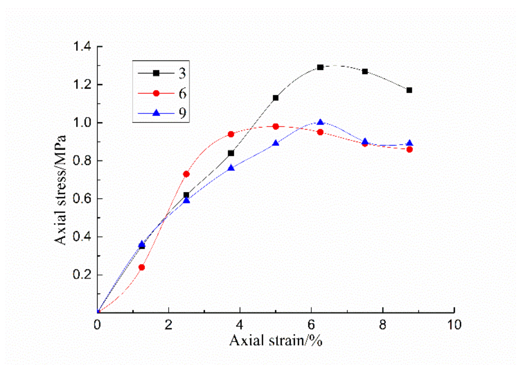
Based on the unconfined compression test, and the relationship between the unconfined compressive strength and the deformation of the concretion body was analyzed, the limit strain was also studied. The relationship between the unconfined compressive strength and axial deformation is shown in Figure 15 (a), (b), and (c). The three graphs correspond to the 9 groups in the orthogonal tables, which are divided into three groups according to the proportion of the cement added.



(a) cement content of 16%



(b) cement content of 20%



(c) cement content of 24%

Figure 15: Unconfined stress-strain curve of the concretion body

It can be seen that the vertical limit strain range of the concretion body is 3.68%~6.42% from Figure 15. The change of the stress and the strain is similar to the soil, and it can be approximated as a linear change at the initial stage of the pressure. This stage can be regarded as the elastic stage of the concretion body; After the pressing process, the axial strain gradually becomes slow, the compressive strength increases gradually, and the curve is stable after reaching the maximum strength. The results show that the failure mode of PBFC slurry is plastic failure. The PBFC slurry has good mechanical properties, and it can adapt to the deformation of the surrounding soil requirements in a certain range.

7 Conclusion

(1) The bentonite-cement impervious slurry obtained by using polyvinyl alcohol as a modifier has a higher anti-seepage property, and its permeability coefficient is between 0.53×10^{-8} cm/s and 1.86×10^{-8} cm/s, the modified effect of polyvinyl alcohol on bentonite

is obvious. The best combination of PBFC anti-seepage slurry is 20% cement, 22% bentonite, 0.2% polyvinyl alcohol, 0.03% superplasticizer.

(2) After the modification of bentonite by polyvinyl alcohol, a dense and high viscosity film is formed on the surface of bentonite. At the same time, due to the dispersion effect and suspension effect of bentonite, the particles distribute evenly, and the bonding force between them is greater, and the density of structure is increased, so that their impermeability is improved. The interlayer structure of bentonite is improved, and the porosity and specific surface area of bentonite are increased, and its adsorption property is improved.

(3) The PBFC anti-seepage slurry has good adsorption performance. The blocking rate of COD_{cr}, BOD_5, NH_4-N, TP, SS was more than 85%, and the blocking rate of heavy metal ions (such as Hg and Pb) was more than 99%. It can resist the erosion of acid liquid and groundwater.

(4) After modified by polyvinyl alcohol, the anti-seepage grouting material has excellent corrosion resistance and durability to heavy metals and organic pollutants. No matter is the erosion of leachate, heavy metal solution or solution of phthalate esters in landfill, the slurry concretion body quality variables are not more than 1%. The surface of the specimen after soaking is dense and complete, and there is no crack in the specimen. The modified slurry concretion body has good stability, durability and corrosion resistance to the erosion of landfill leachate, phthalate solution and heavy metals solution, and can fully meet the requirements of anti-seepage wall durability index.

(5) The unconfined compressive strength of PBFC slurry is mainly determined by the amount of cement, while bentonite, superplasticizer and polyvinyl alcohol have relatively little influence on the strength of cemented body. The unconfined compressive strength of PBFC concretion body after 28 days was 0.5~1.5 MPa, the axial ultimate strain range was 3.68%~6.42%. The stress-strain curve of the slurry concretion body is similar to the stress-strain curve of the soil. When the maximum stress intensity is reached, the curve decreases steadily instead of a sudden drop. The consolidation body of the impervious slurry material has obvious plastic degeneration characteristics, and its failure form is plastic failure.

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