ANALYSIS ON THE BASIC PROPERTIES OF PBFC ANTI-SEEPAGE SLURRY IN LANDFILL

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Abstract. The PBFC anti-seepage slurry formula with polyvinyl alcohol modified bentonite as primary materials were optimized by orthogonal test for solving the leakage problem of landfill leachate effectively and forming the effective isolation in the landfill. The seepage prevention performance, permeability properties and mechanical properties were studied through a series of laboratory experiments. The influence of various factors on the permeability properties and mechanical properties was analyzed and the modified principle of polyvinyl alcohol on bentonite was explored. The results indicated that the concretion bodies of PBFC anti-seepage slurry after 28 days have a good anti-seepage performance, and the average permeability coefficient was less than 10^{-7} cm/s; With 0.5-1.5 MPa unconfined compressive strength and 3.68 - 6.42 % axial ultimate strain range, the PBFC anti-seepage slurry can be compatible with the surrounding soil deformation and meet the requirements of the landfill.
Keywords: *diaphragm wall, seepage resistance, mechanical property, environment, pollution*

Introduction

Large amounts of waste have been generated in the development of modern cities, which has had a great effect on the urban environment (Sun et al., 2008). The disposal of rubbish is becoming more and more important with the increase of rubbish variety and rubbish quantity. Highly polluting garbage will pollute the atmosphere, soil and water resources, and will bring great harm to the ecological environment in the process of collection and processing (Collins, 1998). At present, sanitary landfill is the main method for municipal waste disposal. The garbage and the toxic substances are often mixed and landfilled during the process of landfill. It resulted in a large number of highly polluted leachate and caused serious damage to the underground water source and surrounding soil (Yao et al., 2010). Therefore, it is very important to establish 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 leachate from spreading to the surrounding soil (Guo et al., 2010).

A large number of researches have been conducted since James (1977) found that the major potential environmental impacts related to landfill leachate were the pollution of groundwater and surface waters in 1977. Frost and Griffin (1977) observed the absorption of heavy metals from a municipal landfill leachate by kaolinite and montmorillonite was dependent upon the pH and the ionic strength of the leachate. Kogovsek and Petric (2013) experimented on three landfill sites in karst areas by tracer tests, concluding that landfill leachate could increase the dissolution of limestone and result in the increase of vulnerability of karst aquifers. Many methods have been proposed to prevent the spread of pollution from landfill leachate to surrounding

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environment. For the dredging spoil from the sea canal, Loxham and Westrate (1985) proposed the use of cement-bentonite anti-seepage wall to contain possible pollutants. The results of calculations show that it is effective to conduct a cement-bentonite screen down to a 25m thick clay layer under the surface. Koch (2002) expanded the use of bentonite in landfills and put forward that the success of a containment barrier was depending on the properties of the various mixing components like bentonite, cement, filler, additive and water. Low permeability in the range of 10^{-9} cm/s till 10^{-10} cm/s can be achieved. However, a great deal of emerging contaminants have appeared with the development of the times. Ramakrishnan et al. (2015) introduced the broad categories of emerging contaminants, including pharmaceuticals, personal care products, surfactants, plasticizers, fire retardants, pesticides and nanomaterials. To improve the function of the cut-off wall of municipal solid waste landfill and prevent the damaging from the leachate to the surrounding environment, a new anti-seepage wall formula is found through experiments.

Generally, the landfill anti-seepage wall is consisted of bentonite, cement and fly ash (Xue et al., 2013). The ability of bentonite to adsorb organic pollutants will decrease because of the flocculation and shrinkage of organo bentonite under the action of high concentration organic leachate (Wilkinson et al., 2018). The microstructure and the properties of particles can be improved by using the organic modifier, based on the physical properties of bentonite and the characteristics of interlayer structure (Ross and Shannon, 1926) so that the impervious slurry can control the pollutant effectively while having good anti-seepage performance (Xia et al., 2003; Han and Yue, 2011). Therefore, the new type of PBFC slurry was prepared by using polyvinyl alcohol on the basis of the existing anti-seepage slurry. The PBFC slurry can intercept organic pollutants and heavy metal ions in the filtrate effectively with the good impermeability and mechanical properties. It also can be coordinated with the surrounding soil deformation, meet the requirements of mechanical impervious wall. Thus, it has broad application prospects.

Analysis of anti-seepage performance

Experimental material

The main materials of test slurry were modified bentonite (treated by polyvinyl alcohol), ordinary portland cement and second-quality fly ash. The sodium carbonate and polycarboxylate superplasticizer were added. Grout material requirements were as follows: Bentonite: calcium bentonite after treatment of sodium, 55 – 90 % montmorillonite content; Fly ash: ordinary second-quality fly ash produced by heat-engine plant; Cement: 42.5 grade ordinary portland cement; Polyvinyl alcohol: type 1788 (or 2788); Polycarboxylate superplasticizer: type TOJ800-10A; Soda ash: anhydrous sodium carbonate.

Experimental methods

The slurry with different ratio will affect its impervious performance and mechanical performance. Through the statistical analysis of the existing anti-seepage material of landfill (Dai and Kun, 2011), a preliminary test of this subject was carried out. The orthogonal test of 4 factors and 3 levels was adopted to optimize the slurry formula.The addition of cement, bentonite, water reducer and polyvinyl alcohol was adjusted from

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three different levels to explore the effect of different components on the performance of the slurry. The specific experimental arrangement is shown in *Table 1*.

Table 1. *Proportioning scheme of slurry in orthogonal test*

number	percentage of each factor (%)					
	cement	bentonite	superplasticizer	polyvinyl alcohol	fly ash	soda ash
1	16	18	0.01	0.2	18	0.5
2	16	22	0.02	0.5	18	0.5
3	16	26	0.03	0.8	18	0.5
4	20	18	0.02	0.8	18	0.5
5	20	22	0.03	0.2	18	0.5
6	20	26	0.01	0.5	18	0.5
7	24	18	0.03	0.5	18	0.5
8	24	22	0.01	0.8	18	0.5
9	24	26	0.02	0.2	18	0.5

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.

Experimental results

By using TST-55 variable head permeameter, the permeability experiments of the slurry concretion body with different proportions were carried out (Broderick and Daniel, 1990). The permeability coefficient of the slurry concretion body was measured after 7 days and 28 days, and the result is summarized in *Fig. 1*.

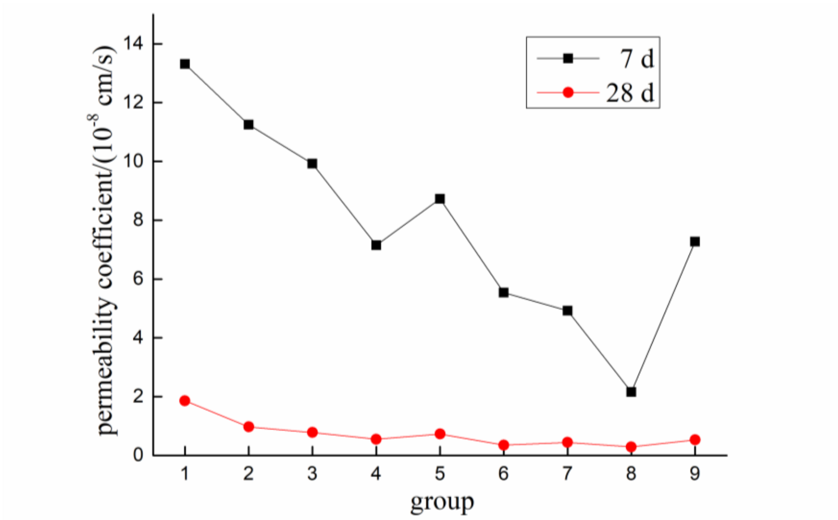

Figure 1. *Variation of permeability coefficient with age*

Comparative analysis of permeability coefficients at different ages

Fig. 1 shows the time-varying law of the permeability coefficient of concretion bodies at a different ratio. The permeability coefficient of the test block after 28 days was obviously less than that after 7 days. The structure of the consolidated body is

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dense with the progress of cement hydration reaction. The hydration product produced by the cement hydration reaction and the bentonite particles are bonded together to form a network structure, which enhances the bonding between the particles and reduces the porosity of the consolidated body, thereby significantly reducing the permeability coefficient (Darweesh and Nagieb, 2008; Holmboe et al., 2012).

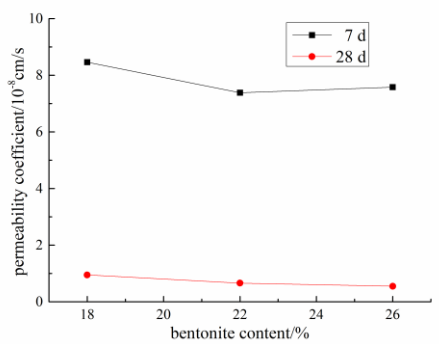
The hardening reaction and the hydration reaction are the major causes of this change (Liu et al., 2010). At the hardening reaction stage, a large number of gel and crystal body were formed within the impervious grouting after the hard condensation reaction and coalescence effect of bentonite, hydration reaction of cement, pozzolanic reaction of fly ash, etc. (Luan et al., 2010). The gel was mainly formed by calcium silicate colloid, and the crystal was mainly composed of ettringite and calcium hydroxide crystals. A special mesh structure was generated due to the development of these products (agglomerates, gel and crystal), it provides space for inert particles that are not readily reactive in colloids. Tightly consolidated bodies are formed in this network structure because a large number of unreacted particles are filled in holes.

Large amount of C-S-H gel has been produced because of the secondary hydration of bentonite particles, which increases the density of the voids in the structure further (Montes-Hernandez et al., 2005). The combined crystal structure was co-hardened under the common conditions of air and water. It was difficult for the microparticles to enter the environment, which means good impermeability (Wen, 1999).

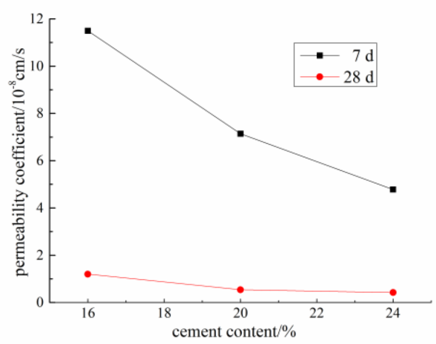
The volcanic ash reaction is caused by the addition of regulator and fly ash (Tigue et al., 2018). It can improve the density of concretion body from two aspects: one is the hydrated film between cement and fly ash which has been filled with the active material produced by the reaction, and the other is the inactive particles in the fly ash which are gradually densified in the honeycomb structure formed by the bentonite and the cement (Wang et al., 2005). Therefore, the permeability coefficient of the consolidation after 7 days and 28 days is quite different.

The influence of various factors on permeability coefficient

The difference range of each factor at the same level is used to reflect the influence of the horizontal variation of each factor on the orthogonal experimental results. By comparing and analyzing the permeability coefficients of the slurry consolidation at different levels at 7d and 28d, the results are shown in *Fig. 2a,b,c,d*.



(a) effect of cement on permeability coefficient



(b) effect of bentonite on permeability coefficient

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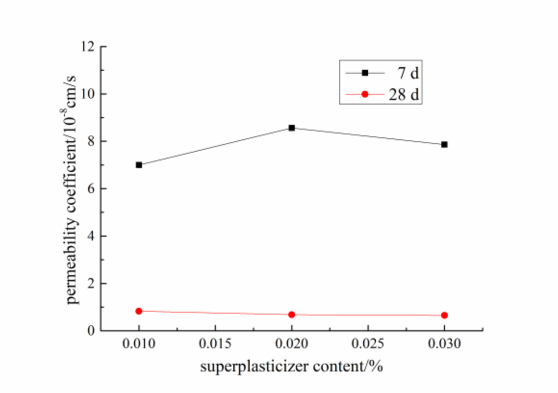
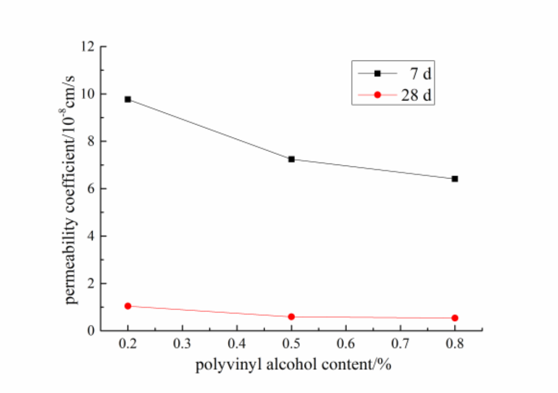


(c) *effect of superplasticizer on permeability coefficient*



(d) *effect of polyvinyl alcohol on permeability coefficient*

Figure 2. *The influence of various factors on the permeability coefficient*

Table 2. *Results of the analysis of the permeability coefficient*

factor	permeability coefficient /10^{-8}cm/s (7d/28d)			
	S_1	S_2	S_3	range R
cement	11.49/1.20	7.14/0.54	4.78/0.42	6.71/0.78
bentonite	8.46/0.95	7.38/0.66	7.58/0.55	0.88/0.40
superplasticizer	7.00/0.83	8.56/0.68	7.86/0.65	1.56/0.18
polyvinyl alcohol	9.77/1.04	7.24/0.59	6.41/0.54	3.36/0.50

Note: The three levels S_1, S_2 and S_3 represent the experimental factors respectively, representing the level from small to large. Such as cement, S_1, S_2 and S_3 are three levels 16%, 20%, 24% respectively

The change of the permeability coefficient is shown in *Fig. 2*. With the increase of cement content, bentonite content and polyvinyl alcohol content, the permeability coefficient of the concretion body after 7 days and 28 days decreases. The decreasing trend slows down with the increase of the content of the component. For the concretion body after 28 days, 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 combination of the range is the fifth group of formulas, among which the content of each component is: 20% cement, 22% bentonite, 0.2% polyvinyl alcohol and 0.03% polycarboxylate superplasticizer.

Analysis of mechanical properties

Test program

The practical application of landfills needs to meet the impervious and mechanical properties (Cheng et al., 2007), so the slurry formula for testing mechanical properties is the same as the slurry formulation for testing impermeability. Based on the orthogonal experimental formula shown in *Table 1*, the mechanical properties of the slurry concretion body were analyzed. The untested compression test was carried out on the test block which reached the corresponding curing period. The sample size was 7 cm in diameter and 4 cm in height. The unconfined compression and deformation test loading rate was 0.5 mm/min.

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Analysis of unconfined compressive strength

The nine groups of concretion bodies after 28 days were tested, and *Fig. 3* shows the experimental result.

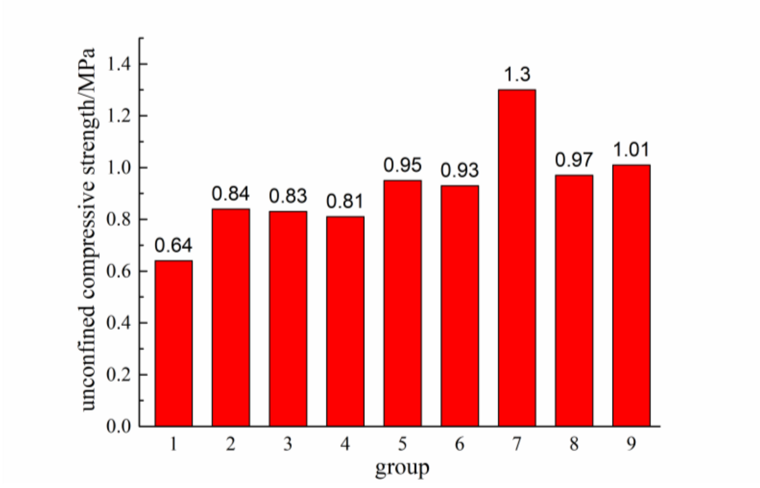
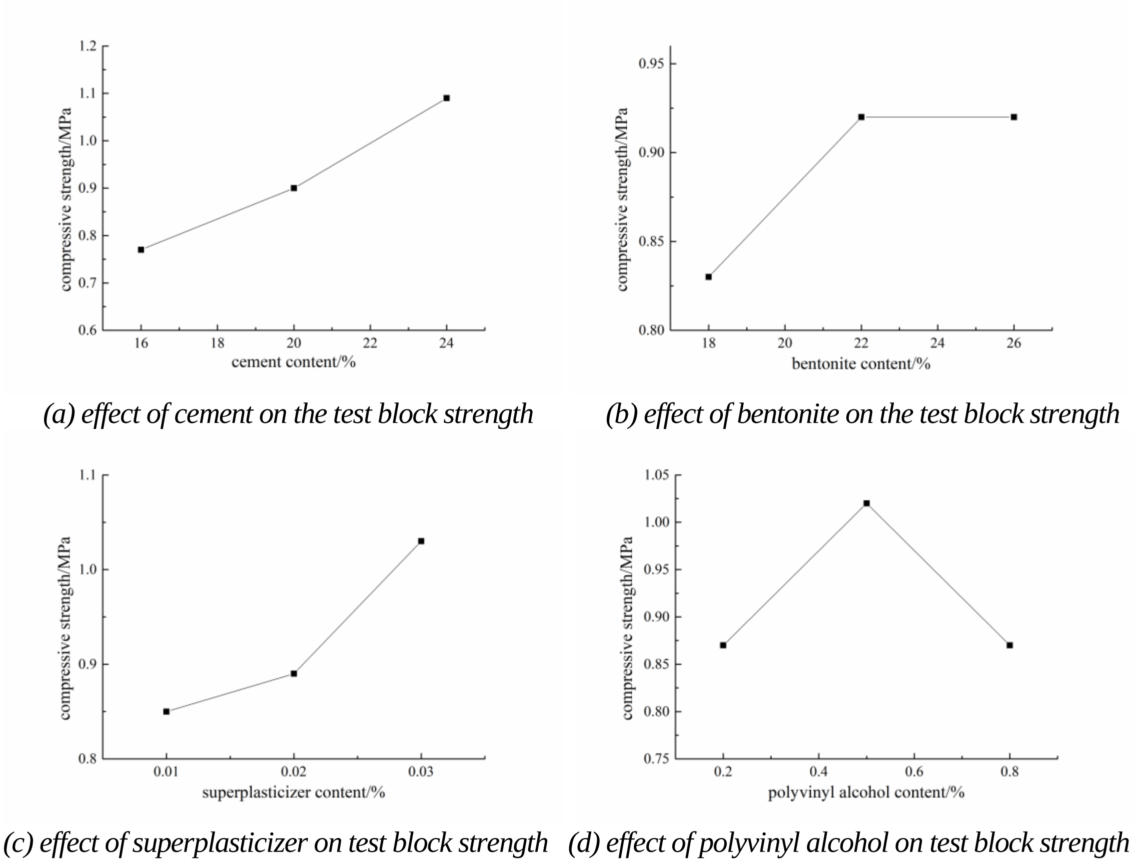


Figure 3. *Variation of unconfined compressive strength with the ratio*

The results of the orthogonal test were treated by the method of extreme value, and the results are shown in *Table 3*. 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 *Fig. 4a,b,c,d*.



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

(c) effect of superplasticizer on test block strength *(d) effect of polyvinyl alcohol on test block strength*

Figure 4. *The influence of various factors on the compressive strength of the concretion body*

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Table 3. *Analysis of compressive strength of slurry concretion body*

factor	unconfined compressive strength (28 d)			
	S_1	**S_2**	**S_3**	**range R**
cement	0.77	0.9	1.09	0.32
bentonite	0.83	0.92	0.92	0.09
superplasticizer	0.85	0.89	1.03	0.18
polyvinyl alcohol	0.87	1.02	0.87	0.15

Note: Three levels of S_1, S_2 and S_3 respectively represent the experimental factors, which represent the level are from small to large. such as cement, S_1, S_2, S_3 respectively three levels of 16 %, 20 %, 24 %.

As can be seen from *Fig. 4*, the influence of different factors on unconfined compressive strength of the concretion body is different. The compressive strength of the consolidated body increases with the increase of cement, bentonite and water reducer, but decreases with the increase of polyvinyl alcohol to a certain value. The influence of unconfined compressive strength of the concretion body from large to small is as follows: cement, water reducer, polyvinyl alcohol, bentonite.

The main reason why the unconfined compressive strength of cement increases is that it increases the compactness of the sample structure (Wang et al., 2015). Cement is the main component of the structure framework of the consolidation body. The increase of cement dosage makes the internal framework of the consolidation body more compact (Marar and Eren, 2011). The hydration reaction of cement produces a large number of stable gels. These gums are stable in nature. The bulk particles can adsorb each other and form aggregates to fill the pores, thus further improving the compressive strength of the slurry consolidation (Su et al., 2011). The effect of water reducer on unconfined compressive strength of consolidated body is mainly due to its reduction of water cement ratio, improvement of uniformity and pore structure of consolidated body, reduction of internal pore volume and compactness of consolidated body, thus improving unconfined compressive strength of consolidated body (İşçi et al., 2006).

Analysis of unconfined stress and deformation

Based on the unconfined compression test and the relationship between the unconfined compressive strength, the deformation of the concretion body was analyzed and the limit strain was also studied. The corresponding values of stress and deformation values are shown in *Table 4*.

Table 4. *Unconfined stress and its corresponding strain value of the concretion body*

strain/%		stress/ MPa								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.25		0.22	0.12	0.02	0.06	0.18	0.07	0.35	0.24	0.36
2.50		0.49	0.35	0.06	0.21	0.64	0.30	0.62	0.73	0.59
3.75		0.60	0.84	0.33	0.73	0.82	0.90	0.84	0.94	0.76
5.00		0.63	0.82	0.72	0.73	0.91	0.82	1.13	0.98	0.89
6.25		0.58	0.70	0.81	0.67	0.83	0.73	1.29	0.95	1.00
7.50		0.60	0.63	0.73	0.64	0.84	0.72	1.27	0.89	0.90
8.75		0.58	0.58	0.67	0.57	0.80	0.62	1.17	0.86	0.89
sample size	diameter	70	70	70	70	70	70	70	70	70
/mm	height	47	47	48	48	48	50	47	49	48

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The test blocks were divided into three groups according to the different cement content. The relationship between the unconfined compressive strength and axial deformation was analyzed, and the second groups, fifth groups and seventh groups are taken as examples. The results are shown in *Fig. 5*.

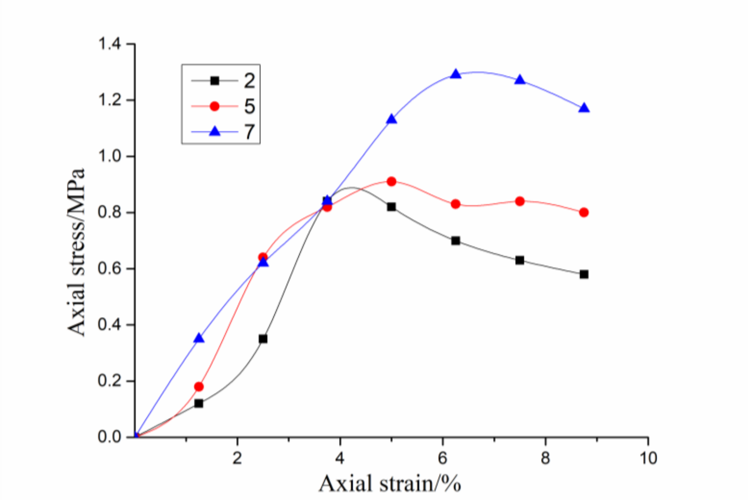

***Figure 5.** Unconfined stress-strain curve of the concretion body*

It can be seen that the vertical limit strain range of the concretion body is 3.68 -6.42 % from *Fig. 5*. 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 (Abdelgader and Górski, 2003). 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 .

Three kinds of BFC slurry with different amount of cement were prepared for comparing the difference of the mechanical properties between PBFC anti-seepage slurry and ordinary BFC slurry. The specific formula and the sample size were shown in *Table 5*. The stress-strain curves were obtained through the unconfined compression test, as shown in *Fig. 6*.

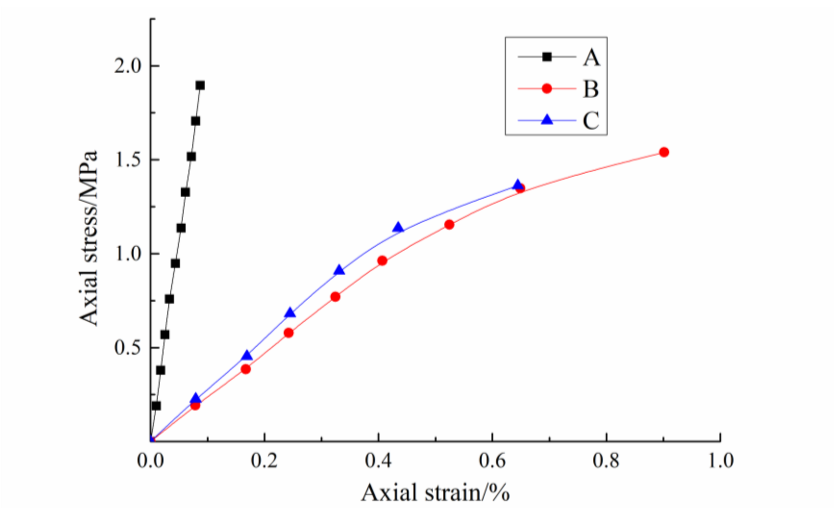

***Figure 6.** Stress-strain curves of the three kinds BFC slurry*

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Table 5. *The ratio and index of three kinds BFC slurry*

number	slurry composition(/g,ml)						sample size/mm	
	clay	**cement**	**Fly ash**	**Na_2CO_3**	**FCLS**	**water**	**diameter**	**height**
A	250	180	230	18	4.5	731	39	63.5
B	220	220	220	12	4	734	30.5	63
C	200	350	230	14	4	693	29	58

Compared with *Fig. 5* and *Fig. 6*, the strain capacity of polyvinyl alcohol modified PBFC slurry has a greater improvement than that of ordinary BFC slurry. The limit strain of PBFC slurry solidified body is about 5 %, while the conventional BFC slurry consolidation has a peak at 1 % strain. This is because the spatial structure and particle surface properties of the bentonite have been improved by polyvinyl alcohol (Ji et al., 2011). The ductility of the concretion body has been improved because the structural pore was filled with polyvinyl alcohol. The PBFC slurry has good mechanical properties, and it can adapt to the deformation of the surrounding soil requirements in a certain range.

Conclusion

1. The orthogonal experiment showed that the descending order of the influence of various factors on the permeability coefficient is cement, polyvinyl alcohol, bentonite, superplasticizer. The influence of polyvinyl alcohol on the permeability coefficient is higher than bentonite, and the bentonite was modified significantly. The optimal level of PBFC anti-seepage slurry PBFC is (mass percentage) 18-24% cement, 19 – 26 % bentonite, 0.2-0.8% polyvinyl alcohol and 0.01-0.03% superplasticizer. The best combination is 20% cement, 22% bentonite, 0.2% polyvinyl alcohol and 0.03% superplasticizer.
2. The anti-seepage performance of PBFC slurry is affected by the curing period. The longer the curing period, the smaller the permeability coefficient of the concretion body. The average permeability coefficient of the PBFC concretion body after 28 days is less than 10^{-7}cm/s, and the permeability is stable.
3. The unconfined compressive strength of PBFC concretion body after 28 days was 0.5-1.5MPa, and the axial ultimate strain range was 3.68-6.42%. The strain of the concretion body has obvious plastic deformation characteristics, and the PBFC slurry can coordinate with the ground deformation of the landfill.

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