Experimental Study on Impermeability of Impervious Slurry in Landfill

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Abstract. The quantity and harmful ingredients of municipal solid waste are increased with the acceleration of urbanization which sets a higher request to the impervious performance of landfill. This paper takes the method of orthogonal experiment to prepare impervious material based on the modified bentonite. The effects of main components on the impervious properties are also researched. The experiment shows that critical aperture of the impervious slurry will reduce with the increase of cement and bentonite. This will enhance the impermeability of the slurry. The influence of cement on the permeability is more significant than that of bentonite. The experiment also finds that the permeability of the pulp reduces with the increase of Na2CO3 and polyvinyl alcohol (PVA). In the microstructure, the number of macropores and the critical aperture increases with the increase of Na2CO3 and PVA. This results in the improvement of permeability for impervious slurry.

1 Introduce

Municipal solid waste will increase dramatically with the development of urbanization. According to statistics, the output of municipal solid waste is 1.3 billion tons so far and expected to reach 2.2 billion tons by 2050 in the world [1,2]. The landfill is widely used at home and abroad because of its characteristics of simple and low running cost [3]. However, a great quantity of leachate with high pollution will be produced in the progress of landfill. This would bring secondary pollution on surrounding soil and water if it cannot be handled properly [4]. The measures and materials of anti-seepage are the key to preventing pollution. It has been proved that taking curtain grouting technology to build anti-seepage system around the landfill site is one of the most effective way to prevent harmful ingredients migrating from leachate to outside [5].

Plee [6] has done the research of microstructure, osmotic coefficient and flowing property on the cement-bentonite slurry. He finds that the large amount of Ca2+ in cement and high pH value of mixed liquor will affect the macroscopic property of slurry. Schoenfelder [7] takes the NMR method to analyze the hardening characteristics and permeability of the cement-bentonite slurry with different mixture ratios. Rafalski [8] and Jefferis [9] have also studied the anti-seepage performance of the mud wall with cement, bentonite and fly ash used in European and American.

Raw bentonite can only effectively prevent the migration of low tension leachate[10,11]. It will
floculate and shrink under the action of high concentration organic leachate. This will result in the rapid decline of its ability to adsorb organic pollutant [12]. It can use organic modifier to improve microstructure and particle surface properties of bentonite because of its interlayer structure and physical properties [13, 14]. 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 [15]. Therefore, it is of great practical significance to do research on the impervious properties of the antiseepage slurry based on the modified bentonite.

2. Experiment

2.1. Raw materials
In this work, the raw materials are as follows: the bentonite should take the treatment of sodium, the type of cement is 42.5 grade ordinary portland cement, the grade of fly ash which is produced in heat-engine plant is I level, the type of polycarboxylate superplasticizer is PCA-300P, the type of PVA is 1788, the Na₂CO₃ and AlCl₃ is analytically pure.

2.2. The method of experiment
Firstly, the experiment uses PVA, Na₂CO₃ and AlCl₃ to modified the bentonite. Secondly, it mixes the modified bentonite, cement, fly ash and water reducer to prepare the samples which the experiment needs. Lastly, the osmotic coefficient of the samples is tested by the variable water level method to evaluate the permeability of the slurry.

3. Results and Discussion

3.1. Orthogonal experiment
The factors and levels of orthogonal experiment are determined by contrastive experiments and the osmotic coefficient for 7 days and 28 days is tested (Table 1 and Table 2).

| Level | Factors (g) | 7d  | 28d |
|-------|-------------|-----|-----|
|       | Cement      | Bentonite | Na₂CO₃ | PVA |
| 1     | 180         | 180 | 1 | 1 |
| 2     | 200         | 190 | 2 | 2 |
| 3     | 220         | 200 | 3 | 3 |

Table 1. The experimental factors and levels of slurry.

| Number | The amount of various factors (g) | Osmotic coefficient (cm/s) |
|--------|----------------------------------|-----------------------------|
|        | Cement  | Bentonite | Na₂CO₃ | PVA | 7d  | 28d |
|        |         |           |       |     | 10⁻⁶ | 10⁻⁸ |
| 1      | 180     | 180       | 3     | 2   | 8.1  | 2.1 |
| 2      | 200     | 180       | 1     | 1   | 4.7  | 1.3 |
| 3      | 220     | 180       | 2     | 3   | 2.7  | 1.8 |
| 4      | 180     | 190       | 2     | 1   | 5.1  | 1.6 |
| 5      | 200     | 190       | 3     | 3   | 1.4  | 3.1 |
| 6      | 220     | 190       | 1     | 2   | 4.4  | 3.9 |
| 7      | 180     | 200       | 1     | 3   | 4.5  | 8.0 |
| 8      | 200     | 200       | 2     | 2   | 5.6  | 3.5 |
| 9      | 220     | 200       | 3     | 1   | 0.6  | 1.0 |

Table 2. The arrangement and test results of orthogonal experiment for slurry.

*Other admixtures: fly ash 180 g, water reducer 0.5 g, AlCl₃ 1.5 g.

It shows that the osmotic coefficient is from 10⁻⁶ to 10⁻⁷ cm/s for 7 days (Table 2). However, the osmotic coefficient of the slurry reaches 10⁻⁸ cm/s for 28 days which meets the Standard for Pollution
Control on the Landfill Site of Municipal Solid Waste.
This paper takes the range method to analyze the results of the orthogonal experiment (Table 3 and Table 4).

**Table 3.** The results of the analysis of osmotic coefficient for 7 days.

| Factors | Cement | Bentonite | Na$_2$CO$_3$ | PVA |
|---------|--------|-----------|--------------|-----|
| Osmotic coefficient $10^{-5}$ cm/s | | | | |
| K1 | 2.0 | 1.6 | 1.4 | 1.0 |
| K2 | 2.0 | 2.4 | 1.3 | 1.8 |
| K3 | 0.8 | 1.1 | 2.3 | 2.1 |
| Range | 1.2 | 1.3 | 1.0 | 1.1 |

**Table 4.** The results of the analysis of osmotic coefficient for 28 days.

| Factors | Cement | Bentonite | Na$_2$CO$_3$ | PVA |
|---------|--------|-----------|--------------|-----|
| Osmotic coefficient $10^{-8}$ cm/s | | | | |
| K1 | 10.0 | 5.2 | 13.2 | 3.9 |
| K2 | 8.0 | 8.6 | 6.9 | 9.5 |
| K3 | 3.0 | 1.3 | 6.2 | 12.9 |
| Range | 3.0 | 7.3 | 7.0 | 9.0 |

On the one hand, the osmotic coefficient decreases with the increase of cement and bentonite and increases with the increase of PVA. On the other hand, the osmotic coefficient increases for 7 days while it decreases for 28 days with the increase of Na$_2$CO$_3$. For 7 days, the order of the effect of various factors on osmotic coefficient is bentonite, cement, PVA and Na$_2$CO$_3$. For 28 days, the order is PVA, bentonite and Na$_2$CO$_3$ and cement. The effect of cement on the osmotic coefficient is more significant than that of bentonite.

3.2. Single factor experiment

3.2.1. The effect of cement and bentonite on the osmotic coefficient of slurry. According to the results of the orthogonal experiment, the experiment controls the cement and bentonite from 180 g to 220 g and the other components are the same (Table 5).

**Table 5.** The results of osmotic coefficient with different amount of cement and bentonite.

| Number | The amount of various factors (g) | Osmotic coefficient (cm/s) |
|--------|----------------------------------|---------------------------|
| | Cement | Bentonite | 7d | 14d | 28d |
| | | | $10^{-6}$ | $10^{-7}$ | $10^{-8}$ |
| A1 | 180 | 190 | 11.0 | 8.2 | 3.1 |
| A2 | 190 | 190 | 8.4 | 6.7 | 2.9 |
| A3 | 200 | 190 | 7.2 | 5.5 | 2.3 |
| A4 | 210 | 190 | 4.2 | 5.1 | 1.8 |
| A5 | 220 | 190 | 2.5 | 4.5 | 1.1 |
| B1 | 200 | 180 | 9.4 | 9.1 | 5.1 |
| B2 | 200 | 190 | 9.2 | 7.0 | 3.5 |
| B3 | 200 | 200 | 9.0 | 6.2 | 2.4 |
| B4 | 200 | 210 | 7.2 | 5.5 | 2.3 |
| B5 | 200 | 220 | 6.6 | 2.6 | 1.8 |
Figure 1. Relation curve of osmotic coefficient and the amount of cement.

Figure 2. Relation curve of osmotic coefficient and the amount of bentonite.

The osmotic coefficient of impervious slurry decreases with the increase of cement and bentonite at all time points (Figure 1 and Figure 2). It is known from the study of Chao Xu [16] that the permeability of slurry is related to the critical aperture which reflects the degree of connectivity of pores and the tortuosity of infiltration paths inside the impervious material. This is the essence of permeability and critical aperture. The hydration products of cement produce more structure of consolidation is more complete with the increase of cement. The bentonite will swell after reacting with water. The macropores decrease and the micropores increase when the bentonite is increased. This results in the further reducing of critical aperture and the number of connected pore which explains the decrease of osmotic coefficient with the increase of cement and bentonite.

3.2.2 The effect of PVA and Na2CO3 on the osmotic coefficient of slurry. The white floc will be produced after reacting between excessive Na2CO3 and PVA. The modification on bentonite is changed in that situation. The best ratio of Na2CO3 and PVA which is summarized from a lot of experiments is 1:1. According to the results of the orthogonal experiment, the experiment controls the Na2CO3 and PVA from 1.0g to 3.0g and the other components are the same (Table 6).
Table 6. The results of osmotic coefficient with different amount of Na$_2$CO$_3$ and PVA.

| Number | The amount of various factors (g) | Osmotic coefficient (cm/s) |
|--------|----------------------------------|-----------------------------|
|        | Na$_2$CO$_3$ | PVA | 7d $10^{-6}$ | 14d $10^{-7}$ | 28d $10^{-8}$ |
| C1     | 1.0           | 1.0 | 2.8          | 2.3          | 1.2          |
| C2     | 1.5           | 1.5 | 7.0          | 3.7          | 1.9          |
| C3     | 2.0           | 2.0 | 7.2          | 5.5          | 2.3          |
| C4     | 2.5           | 2.5 | 10.0         | 7.9          | 2.6          |
| C5     | 3.0           | 3.0 | 13.0         | 8.5          | 3.1          |

Figure 3. Relation curve of osmotic coefficient and the amount of Na$_2$CO$_3$ and PVA.

The osmotic coefficient of the consolidation increases with the increase of Na$_2$CO$_3$ and PVA (Figure 3). It is known from Weian Kong[17] that the increase of Na$_2$CO$_3$ concentration will reduce the expansion volume of bentonite which increases the permeability of the slurry.

4 Microstructure of the Slurry

The experiment selects three samples of C1, C2 and C3 to further explore the influence of Na$_2$CO$_3$ and PVA on the permeability of slurry. The three samples are tested under scanning electron microscope after drying, crushing and sampling.

It shows the morphology of particles in the enlarged 500 times (Figure 4). Inside the C1 sample, the crystal particles are close, the structural densification is well, the macro pores are few and the critical aperture is small which determine that the permeability of the slurry is excellent. With the increase of Na$_2$CO$_3$ and PVA, the crystal particles are disperse, the structural densification is bad, the macro pores are more and the critical aperture is bigger which determine that the permeability of the slurry is poor.
The Na$_2$CO$_3$ concentration is low when the amount of Na$_2$CO$_3$ is small. In that situation, the bentonite will swell and compact the inter structure of the slurry after absorbing water which results in the low permeability of the impervious slurry. The Na$_2$CO$_3$ concentration will increase when the amount of Na$_2$CO$_3$ increases which represses the water imbibition and expansion of bentonite. The PVA will form a dense polymer film on the surface of bentonite particles and the bentonite particles present hydrophobicity which results in the weakness of impermeability of the impervious slurry.

5 Conclusions
This paper analyzes the relationship between the permeability and each component of the slurry which is based on the influence of components on critical aperture. The conclusions are drawn as follows:

The critical aperture of the impervious slurry will gradually decrease with the increase of cement and bentonite. The effect of cement on the osmotic coefficient is more significant than that of bentonite. The increase of Na$_2$CO$_3$ will repress the water imbibition and expansion of bentonite. The PVA will form a dense polymer film on the surface of bentonite particles and the bentonite particles present hydrophobicity. These reasons cause the decrease of the impermeability of the impervious slurry with the increase of Na$_2$CO$_3$ and PVA. The impermeability of the antiseepage slurry meets the requirements of the current standard and provides the basis for the landfill engineering.

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