Engineering performance’s evaluation of integrated backfill materials

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Abstract. In the process of deep geological disposal, bentonite, illite, zeolite, kaolinite, quartz sand and other materials were used as filling materials for filling in waste tin and rock. This paper proposed integrated backfilling materials (ZBP 8, ZBP 7, ABP 8, ABP 7 and Xinjiang bentonite Na⁺) etc and five groups of formula, with a series of geotechnical experiments measured the engineering properties, such as glial price, expansion solution, liquid limit, plastic limit of compacted expansive, unconfined compressive strength, elastic modulus, Poisson's ratio and coefficient of permeability. Compared with the GMZ-1 bentonite, the engineering performance of various proportions meted the backfill material disposal requirements and could be used as backfill material candidate for the integrated materials, but proportion of zeolite and palygorskite should not be too large, generally better from 20% to 30%. The specific engineering properties were as follows: Under the condition of the same proportion, ABP mixture was higher than the ZBP mixture of liquid limit. In the ABP mixture and the ZBP mixture, dry density at 1.7g/cm³-1.8g/cm³ and moisture content between 15%-20% of the compaction performance were the best. The compaction performance of ZBP mixture was better than that of ABP mixture under the same condition. Different ratio of ZBP and ABP composite minerals under no load condition, it found that ultimately expansion and expansion force with the increase of bentonite. The expansion performance of ABP mixture was better than that of ZBP mixture. Under the same condition, the unconfined compressive strength, elastic modulus and Poisson's ratio increased with the increase of the content of bentonite in the integrated backfill material. Under the condition of 100 MPa compaction, the permeability coefficient of ZBP and ABP mixture was 2 orders of magnitude higher than that of GMZ-1. The permeability coefficient of Xinjiang bentonite under 50MPa was very close to that of GMZ-1 bentonite under 100MPa.

1. Introduction
In deep geological disposal, the buried high-level waste underground projects known as geological disposal repository. The disposal repository was generally designed using a conceptual model of "multiple barrier systems". But the backfill material, as the material filled between the waste container and the geological body, should have strong adsorption, water insulation, thermal conductivity and mechanical buffering performance. The backfill materials studied abroad have been studied for more than 30 years [1, 2, 3]. The main backfill materials studied are bentonite, illite, kaolinite, quartz sand, attapulgite and so on. According to the requirements of high radioactive waste for backfilling materials, Pusch (1977, 1980), through analysis, comparison and relevant experiments, believed that...
bentonite with montmorillonite as the main component was the most suitable material [4, 5]. Due to the differences in structure and composition, Weststic et al. (1982) believed that sodium bentonite was more suitable for backfilling materials than calcium bentonite [6]. Sweden, the United States, Canada and other countries had focused on a large number of laboratory tests and field tests on bentonite. Previous studies had shown that bentonite was an ideal backfilling material, and adding quartz sand to bentonite was conducive to increasing the thermal conductivity [7]. The research in this field in China began in 1986. Through the investigation and screening of bentonite deposits nationwide [8], it was determined that gaomiaozi bentonite deposit in xinghe county, Inner Mongolia was the first choice for the backfilling material supply base of geological disposal repository of high-level radioactive waste in China. However, most of the backfilling materials studied at home and abroad were single minerals, and there were few studies on compound minerals [9, 10]. Cui suli, liu jisheng, zhang huyuan et al. [11] proposed a new concept of bentonite -- sand mixture as high buffer backfilling materials, and achieved certain results.

2. Selection and integration of backfill materials

In previous research, it was found that the mixture of zeolite bentonite (ZB) and attapulgite bentonite (AB) with the ratio of 3:7 and 2:8 had better engineering properties [12, 13]. In order to improve the thermal conductivity of the mixture, 10% pyrite was added to the mixture, and the engineering properties of ZBP7, ZBP8, ABP7 and ABP8 were measured as follows in Table 1. Remarks: Z was zeolite, B was Xinjiang Altay sodium bentonite (the base material of this experiment), P was pyrite, A was attapulgite, XJNa+ was Xinjiang Altay sodium bentonite. The subscript Arabic numeral was the percentage of bentonite in the total mass of the mixture. The basic physical properties of these four groups of mixed soils were compared with those of Gaomiaozi bentonite and Altai bentonite in Xinjiang, as shown in Table 1.

| Mineral | Colloid value (ml/15g) | Swelling capacity (ml/g) | Swelling value (ml/3g) | Liquid limit (%) | Plastic limit (%) | Proportion |
|---------|------------------------|--------------------------|------------------------|-----------------|------------------|------------|
| GMZB-1  | 53-73                  | 9.3-20                   | 8.6-11.8               | 90-120          | 30-44            | 2.4-2.6    |
| ZBP7    | 92                     | 11.0                     | 21.0                   | 73.8            | 37.1             | 2.32       |
| ZBP8    | 92                     | 12.0                     | 25.0                   | 89.9            | 39.5             | 2.51       |
| ABP7    | 94                     | 10.5                     | 23.5                   | 89.5            | 35.6             | 2.12       |
| ABP8    | 97                     | 13.0                     | 26.0                   | 90.5            | 38.5             | 2.23       |
| XJNa+   | >100                   | 28.0                     | 42.0                   | 82.3            | 27.0             | 2.52       |

It could be seen from Table 1 that the colloidal value of the ZBP mixtures and ABP mixtures were higher than that of the bentonite of gaomiaozi in Inner Mongolia. Because the substrate of the mixtures in this paper was the bentonite of altai in xinjiang, whose colloidal value content was >100[12]. At the same time, the swelling capacity and swelling value of altai bentonite (XJNa+), ZBP mixtures and ABP mixtures were larger than those of gaomiaozi bentonite in Inner Mongolia. The result was closely related to the attribute of bentonite and the content of montmorillonite. The reason was that the content of montmorillonite was higher, the colloid value and the expansibility of the mixture were higher, which could effectively block the migration of nuclides from the waste water pool to the external environment. The results showed that the plastic limit, liquid limit and void ratio of ZBP and ABP mixtures were also close to those of the Gaomiaozi bentonite (GMZB), which could meet the requirements of backfill materials.
3. Comprehensive evaluation of engineering performance of integrated backfill materials

3.1. Comparison of compaction performance

In this paper, the sample of the outer radius was 70 mm, the inner radius was 30 mm, and the height 20 mm was a fan-shaped ring [15], which through self-made mold, using hydraulic universal testing machine, the loading at 0.5 mm of rate. Under the same moisture content and dry density, the compaction load required for compacting backfill material was measured. The results were shown in Table 2 and Figure 1.

Table 2. Compaction performance of integrated material compared with bentonite of Inner Mongol.

| Samples  | Water content (%) | Dry density (g/cm³) | Wet density (g/cm³) | Void ratio | Pressing load (MPa) |
|----------|-------------------|---------------------|---------------------|------------|---------------------|
| GMZB-1 [14] | 15.00            | 1.75                | 2.08                | 22.45      | 35.45               |
| GMZB-2 [16] | 15.21            | 1.72                | 2.02                | 24.04      | 32.65               |
| ZBP8     | 15.66            | 1.68                | 1.94                | 38.10      | 27.36               |
| ZBP7     | 15.96            | 1.71                | 2.02                | 33.33      | 26.43               |
| ABP8     | 15.58            | 1.76                | 2.03                | 31.82      | 27.78               |
| ABP7     | 15.44            | 1.74                | 1.99                | 34.88      | 25.60               |
| XJNa+    | 15.27            | 1.72                | 2.05                | 28.21      | 30.24               |

It can be seen from Figure 1 and Table 2 that the compaction load of Gaomiaozi bentonite was slightly larger at the same moisture content and dry density, which may be caused by the different content of montmorillonite. The compaction characteristics of bentonite were determined by the structure of montmorillonite with water swelling. The higher the content of montmorillonite, the more difficult it was to compact, which was consistent with the result obtained by Liu Yuemiao (2001) [17]. In order to get the same dry density backfill material, a certain amount of zeolite or attapulgite was added to improve the compaction performance of bentonite. Through the research on the compaction molding performance of integrated backfill material, when the compaction load was greater than 50MPa, the compaction dry density changed little with the increase of compaction load [13]. Therefore, when the moisture content was not less than 10% or 25%, the dry density of backfill material was less than 1.7g/cm³, which could be compacted within 50 MPa. In addition, the relationship between the maximum dry density and the optimal moisture content of ZBP moisture or ABP moisture were also obtained by light compaction and heavy compaction. The experimental results showed that adding a certain amount of zeolite or attapulgite could significantly reduce the plasticity index of backfill material, but in the compaction test, it could obtain a larger maximum dry density and a smaller optimal moisture content, so the properties of pure bentonite were improved. Secondly, the experimental results showed that the maximum dry density obtained by heavy compaction was larger than that obtained by light compaction, that was the compaction energy was greater, the sample density was greater, and the water content was smaller. The experimental results were consistent with the research of many foreign scholars [17, 18].

3.2. Comparison of expansion performance

In this paper, the integrated backfill material samples were prepared according to the optimal moisture content, the prefabricated dry density of samples were about 1.7g/cm³, and the compaction load was 20MPa. Five groups of mixtures, such as ZBP, ABP and xjna +, were put into the dilatometer to adjust the initial reading of the meter. Then, distilled water was slowly injected to measure the expansion rate and the expansion force of the integrated backfill material under load condition without load. The results were shown in Figure 2 and Table 3.
Figure 1. Compaction performance of the backfill material with Inner Mongolia bentonite.

Figure 2. Backfill materials and swelling properties of bentonite in Inner Mongolia.

Table 3. Compaction and swelling performance of integrated material.

| Samples | Pressing load (MPa) | Moisture content (%) | Wet density (g/cm³) | Compaction density (g/cm³) | Final expansion rate (%) | Expansion force (MPa) |
|---------|---------------------|----------------------|---------------------|---------------------------|-------------------------|----------------------|
| GMZB-1[14] | 20                  | 22.04                | 1.69                | 1.39                      | 25.3                    | 2.7                  |
| GMZB-2[16] | 30                  | 22.04                | 1.73                | 1.46                      | 27.1                    | 2.8                  |
| ZBP₇     | 20                  | 15.37                | 2.01                | 1.74                      | 18.9                    | 1.3                  |
| ZBP₈     | 20                  | 15.78                | 1.99                | 1.72                      | 22.3                    | 1.4                  |
| ABP₇     | 20                  | 15.35                | 1.95                | 1.69                      | 31.4                    | 2.0                  |
| ABP₈     | 20                  | 15.26                | 1.97                | 1.71                      | 32.9                    | 2.5                  |
| XJNa⁺    | 20                  | 15.42                | 1.97                | 1.71                      | 35.6                    | 3.4                  |

It can be seen from Figure 2 and Table 3 that the compacted density of Inner Mongolia bentonite increased with the increase of compressive pressure under the condition of the same water content. Different samples had different densities under the same pressure, which may be due to the different content of montmorillonite in the samples. The higher the content of montmorillonite, the smaller the dry density. In the same ratio, the expansion force of ABP mixture was larger than that of ZBP mixture, mainly because zeolite was non-viscous, while attapulgite contains some montmorillonite. The results also showed that the swelling force of the mixture was not as great as that of Inner Mongolia, which was mainly related to the low content of bentonite in the mixture.

3.3. Compression performance comparison

The samples were prepared according to the volume and dry density calculation required by the quality of the wet earth, and poured the pressure within the sample device, through the electro-hydraulic servo universal testing machine pressure to the required density. The instrument used for the compressive strength test was a hydraulic universal testing machine with the diameter of 61.8 mm and the height of 50 mm. The unconfined compression and deformation tests of compacted bentonite were carried out in accordance with the industrial standard of the People’s Republic of China "rules for rock test of water conservancy and hydropower projects (SL264-2001)". The loading rate of unconfined compression and deformation test was 0.1~0.5 mm/min. Strain gauge method was used for strain measurement. The
unconfined compressive strength, elastic modulus and poisson's ratio of ZBP mixture, ABP mixture and XJNa+ mixture to water content and dry density were measured. The results were shown in Table 4.

Table 4. The unconfined compression properties of the backfill material and Inner Mongolia bentonite.

| Samples       | Moisture content (%) | Dry density (g/cm³) | Unconfined compressive strength (MPa) | Elastic modulus (GPa) | Poisson's ratio |
|---------------|----------------------|---------------------|--------------------------------------|-----------------------|-----------------|
| GMZB-1[14]    | 15.0                 | 1.76                | 4.85                                 | 2.92                  | 0.48            |
| GMZB-2[16]    | 15.0                 | 1.58                | 2.17                                 | 0.99                  | 0.42            |
| ZBP7          | 15.51                | 1.72                | 2.92                                 | 2.52                  | 0.47            |
| ZBP8          | 15.24                | 1.74                | 2.71                                 | 2.59                  | 0.50            |
| ABP7          | 15.31                | 1.71                | 2.53                                 | 2.07                  | 0.55            |
| ABP8          | 15.06                | 1.67                | 2.34                                 | 1.98                  | 0.58            |
| XJNa+         | 15.46                | 1.68                | 2.44                                 | 1.81                  | 0.60            |

It can be seen from Table 4 that under the same moisture content of the gaomiaozi bentonite, the greater the dry density, the greater the unconfined compressive strength and elastic modulus. Under the same condition, the unconfined compressive strength, elastic modulus and poisson ratio of integrated backfill materials increased with the increase of bentonite content in the total mass of the mixture. The differences in the Table 4 may be caused by the bentonite content in the mixture, the particle size and strength of zeolite, bentonite and attapulgite in the mixture. In bentonite content was 70%, the same conditions the unconfined compressive strength and elastic modulus of ABP mixture were higher than ZBP mixture, but the poisson's ratio of ABP mixture were lower than ZBP mixture. This showed that adding attapulgite maked deformation and low intensity easily. It had to do with attapulgite containing a certain amount of montmorillonite, so adding a mixture of zeolite could get greater compressive strength. In addition, at the same dry density, the unconfined compressive strength and elastic modulus decreased with the increase of moisture content, indicating that dry density and moisture content were important factors for the compaction and strength of backfill materials.

It could be seen from Table 5 that under the same dry density, with the increase of the pressure, the permeability coefficient decreased. The difference of pressure between 100MPa and 10MPa was 10 times, and the difference of permeability coefficient was 20~50 times. However, for the same proportion of ABP and ZBP mixture, when the compression load was 50MPa and 100MPa, the permeability difference was not very obvious, which indicated that when the compression load was greater than 50MPa, the mixture could achieve compaction, which was consistent with the compaction performance of the overall backfill material [15]. Secondly, the measured permeability coefficient of integrated ZBP7 mixture and ABP7 mixture was high 2 orders of magnitude than zhen-yao shen [19] Inner Mongolia in 100MPa. However, the measured permeability coefficient of single xinjiang altau bentonite under the pressing load of 50 MPa near zhen-yao shen high temple of bentonite under 100 MPa. The results showed that the permeability of backfill material was related to both dry density and pressure. The higher the pressure and dry density of the mixture in the same proportion, the worse the permeability. It was also related to the mineral composition. Suppose the mixture of 10% pyrite mineral powder could also lead to porosity increased, accelerated the permeability of mixture. Thirdly, under the same conditions of compression load and bentonite proportion of the mineral, permeability coefficient was smaller than ABP mixture. The reason was that the zeolite was non-viscous minerals, did not have water retention, the zeolite increased the porosity, the permeability increased rapidly.
Table 5. The infiltration parameters of the integrated backfill materials with different compaction forces and bentonite in Inner Mongolia.

| Samples   | Pressload (MPa) | Moisture content (%) | Wet density (g/cm³) | Compaction density (g/cm³) | Porosity (%) | Permeability coefficient (10-11cm/s) |
|-----------|-----------------|----------------------|---------------------|-----------------------------|--------------|-------------------------------------|
| GMZB-1[19]| 100             | 20.38                | 2.08                | 1.79                        | 28.7         | 0.01                                |
| XJNa+     | 100             | 15.4                 | 2.08                | 1.68                        | 20.7         | 0.016                               |
| ZBP7      | 100             | 15.80                | 2.11                | 1.82                        | 27.6         | 2.11                                |
| ABP7      | 100             | 15.36                | 2.07                | 1.69                        | 20.23        | 1.15                                |
| ZBP7      | 50              | 15.9                 | 2.01                | 1.70                        | 20.21        | 3.67                                |
| ABP7      | 50              | 15.4                 | 2.13                | 1.69                        | 19.57        | 1.841                               |
| ZBP8      | 50              | 15.5                 | 2.02                | 1.66                        | 20.06        | 0.964                               |
| ABP8      | 50              | 15.2                 | 2.03                | 1.72                        | 20.09        | 0.365                               |
| ZBP7[16]  | 10              | 9.44                 | 2.27                | 2.07                        | 22.24        | 42.68                               |

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4. Conclusion and outlook
Through the author's research in recent years, a certain proportion of integrated backfill material was proposed, and each index could meet the requirements of domestic deep geological disposal of high-level radioactive waste. This paper mainly studied the engineering performance comparison of ZBP7, ZBP8, ABP8, ABP7, Xinjiang Altay bentonite Na+ and with Gaomiaozi bentonite Na+ in Inner Mongolia. The specific conclusions were as follows:

First, taking Xinjiang Na+ bentonite as base material, zeolite, attapulgite, pyrite and other materials could be added into the mixture according to a certain proportion. In the laboratory, zeolite or attapulgite with 20% - 30% content and bentonite with 70% - 80% content were 2:8 and 3:7, and pyrite with 10% content as additive were selected as candidate materials. The engineering performance of each ratio meted the disposal requirements of backfill materials.

Secondly, in ZBP and ABP mixtures, the swelling capacity and gum value increased with the increase of bentonite content. The specific gravity index of the samples was greater than 2, and the plasticity index was greater than 10. The liquid limit of ABP mixture was higher than that of ZBP mixture at the same ratio.
Thirdly, under the conditions of dynamic compaction and static compaction, the best compaction performance could be obtained when the dry density of ZBP and ABP mixture was 1.7 g/cm³–1.8 g/cm³ and the moisture content was 15%-20%. The experimental results showed that the compaction performance of ZBP mixture was better than that of ABP mixture. In practical engineering, it was suggested that the proportion of zeolite mixture or attapulgite mixture should not be too large, generally 20%-30% was better.

Fourthly, by measuring the final expansion of ZBP and ABP mixture with different proportions under no load condition and the expansion force under load condition, it was found that the expansion performance of bentonite was better with the increase of bentonite, and the expansion performance of ABP mixture was better than that of ZBP mixture. In addition, the experiments showed that the initial moisture content, compaction load and dry density had great influence on the expansion amount and expansion force.

Fifthly, the unconfined compressive strength, elastic modulus and Poisson's ratio of different proportions of ZBP and ABP mixture were related to water content and dry density. Under the same conditions, the unconfined compressive strength and elastic modulus of ZBP mixture were much larger than those of ABP mixture, but the Poisson's ratio decreased.

Finally, the results showed that the permeability coefficients of ZBP, ABP and xjna⁺ decreased with the increase of bentonite content at 100MPa or 50MPa, and the change of permeability coefficient with time basically conforms to Darcy's law.

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