

**Development of shotclay system to construct high-quality buffer materials - 9057**

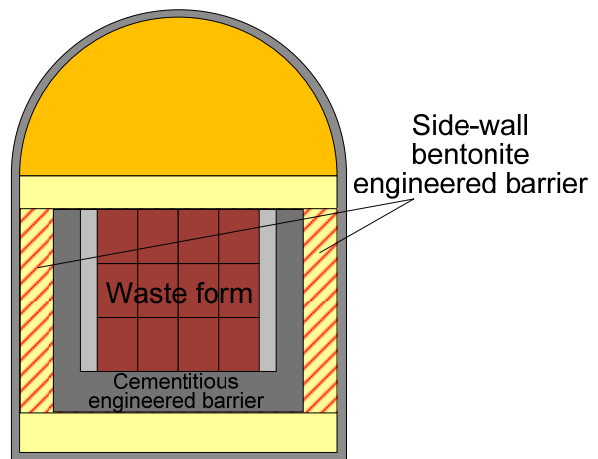
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**ABSTRACT**

This paper describes the result of an experiment of shotclay method which has been developed to construct the high-quality buffer materials in a radioactive waste disposal facility. The shotclay method is a construction method which is conducted by shooting particle-like bentonite material with the supplied energy of high-pressed air. This paper includes a basic idea of this method, features, and results of its key experiments.

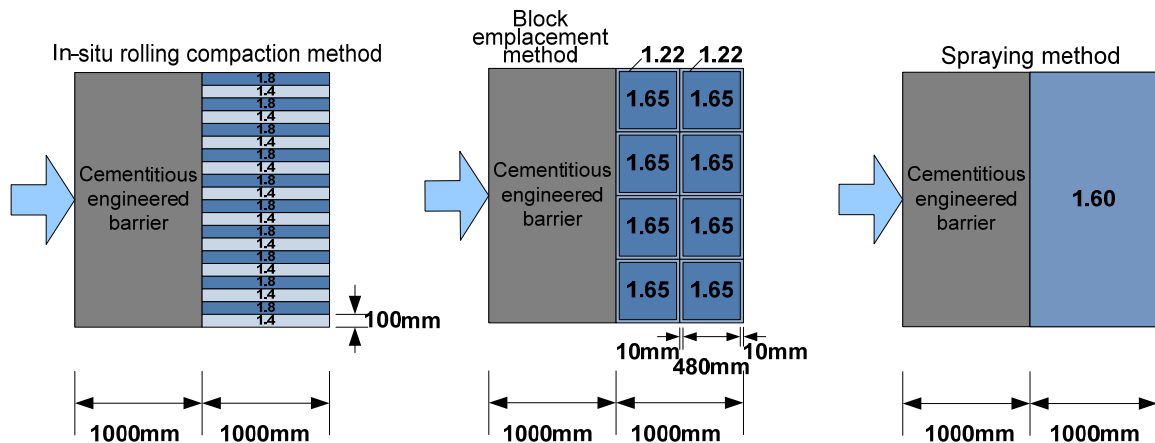
**INTRODUCTION**

To enhance reliability of techniques and safety assessment methods for geological disposal of radioactive waste in Japan, the space between the radioactive waste object and the surrounding rock mass must be tightly compacted with bentonite-contained material [1], which is termed buffer materials or bentonite engineered barrier as shown in Fig. 1. However, as the given space for its construction is limited, such a heavy machine as vibration roller cannot be used in the area. Therefore, another effective method to construct high-density bentonite engineered barriers is required. To achieve this purpose, various methods including in-situ compaction, bentonite block emplacement, and bentonite pellet emplacement were proposed, and they have been investigated to scrutinize their applicability. The result of the investigation showed that each construction method caused its unique pattern of density distributions within constructed bentonite engineered barriers as shown in



**Fig. 1 Conceptual geological disposal facility [2]**

Fig. 2. Up to this time most of the attention concerning the construction quality of the bentonite engineered barrier has been paid to the average of its mass density. This is based on an assumption that bentonite would be swelled by penetration of groundwater and that the density of the bentonite would eventually become homogeneous. As a matter of fact, however, the evaluation of the saturation process and its influence to the performance of the engineered barrier are quite difficult because the phenomenon is chemically, mechanically and hydraulically



**Fig. 2 Density distributions for different construction methods**

complex. Then the shotclay method has been developed to construct the homogeneous bentonite engineered barrier in a radioactive waste disposal facility.

### FUNDAMENTAL FEATURES OF THE SHOTCLAY SYSTEM

Shotclay system is a barrier construction method which is conducted by shooting clay-contented material with energy of high-pressure air [3][4]. The components of machines and tools used for the method are shown in Fig. 3. The equipment consists of an air compressor, material feeder, and sprayer, which are ordinarily used for shotcreting. The spraying material is a roughly crushed bentonite ore with controlled water content and a maximum grain size of about 5 mm.

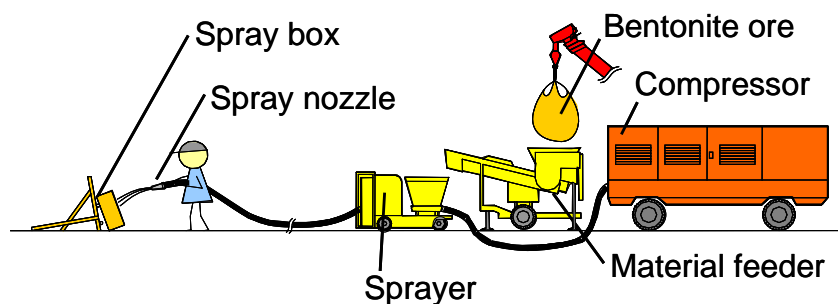


Fig. 3 Components of machines and tools of shotclay method

This system has some advantages following below.

- It can construct the homogeneous bentonite engineered barrier, that is, it can narrow the range of density of constructed buffer materials.
- It can construct the bentonite engineered barrier without continuous gap which possibly becomes a ground water channel.
- It can minutely control the quality of bentonite engineered barrier by changing the flow of air or material.
- It can construct the bentonite engineered barrier in any directions or in any shapes.
- It can construct the bentonite engineered barrier in narrow space because of its small construction system.

If such homogeneous buffer materials can be built up in the actual disposal facilities, we can expect the prescribed permeability just after construction and may leave out the further investigation on the continuous space between buffer materials and surrounding rock mass or in the between buffer materials (i.e. blocks, pellets) which possibly becomes a ground water channel. Thus, the technique of the shotclay method may simplify the procedure of the quality evaluation methods for geological disposal especially in terms of permeability or swelling pressure on saturation process of bentonite material.

### ADVANCEMENT OF THE SHOTCLAY SYSTEM

To make the best use of the shotclay system, several elemental techniques were developed.

#### Application of supersonic nozzle to the shotclay system

The parameters that significantly affect the dry density of bentonite include the method of water content adjustment, nozzle shape, spraying distance, and the amount of supplied material relative to the airflow of the compressor. As shown in Figure 3, the machines used in the shotclay method include a compressor that is also used for shotcrete, a supply machine, and a spray machine. A supersonic nozzle is used for spraying the material at high density. The spray nozzle, which has compression and expansion zones (Figure 4), is designed to increase spray pressure and spray the material onto the target at high speed.

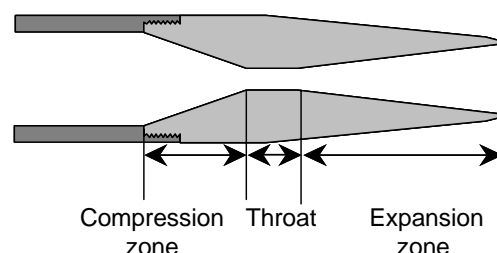
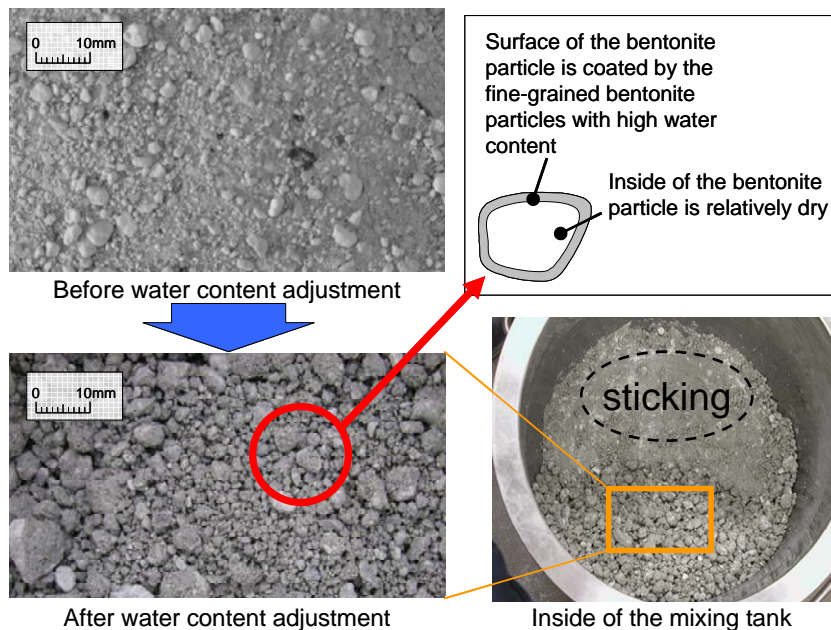


Fig. 4 Longitudinal section of supersonic nozzle

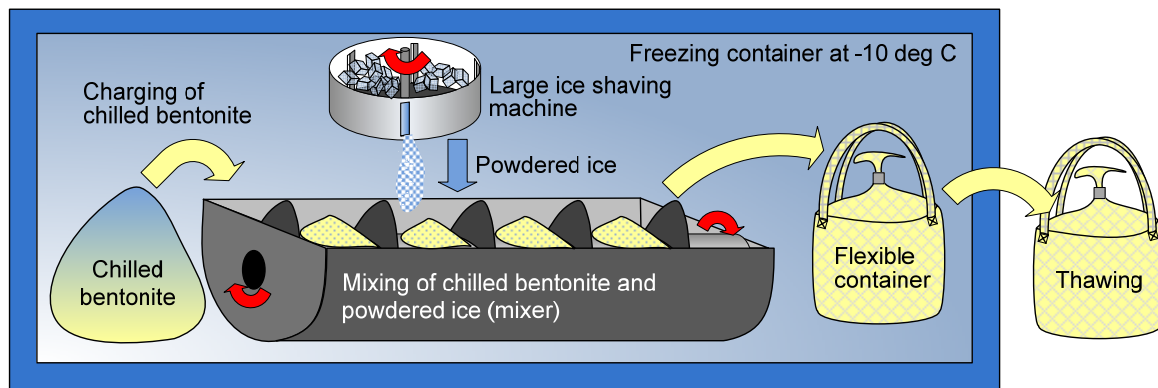
**Development of freeze mixing method for water content adjustment**

The water content and the dry density are the most important parameters for constructing a bentonite engineered barrier in a radioactive waste disposal facility. Water content is generally adjusted by simply mixing the material and water, but it is not easy to mix them homogeneously, and there are many other problems, such as aggregation of the material during the mixing, adherence of the material to the mixing tank, and inhomogeneous distribution of water content (Fig. 5). The aggregation of the bentonite base material during water content adjustment is a serious problem in constructing bentonite engineered barriers by the shotclay method.



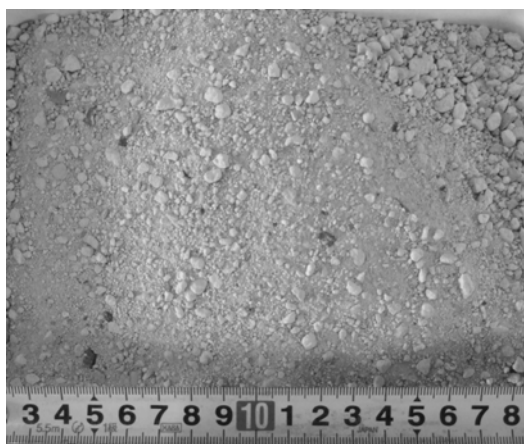
**Fig. 5 Problems of conventional water content adjustment method**

The authors have developed the freeze mixing method for the water content adjustment [5]. The procedure is shown in Figure 6. The method is carried out in a freezing facility. A freeze mixing plant consists of an ice maker, an ice crusher, and a mixing machine. They are set in the freezing facility and cooled before the mixing operation. In the freeze mixing method, powdered ice and bentonite cooled in the freezing facility for about one day are prepared. The powdered ice and bentonite are both cooled to  $-10^{\circ}\text{C}$  or lower, so that the ice will not be melted by frictional heat generated during mixing. The temperature in the freezing facility is also kept at about  $-10^{\circ}\text{C}$ . Under these conditions, the ice and bentonite can be mixed easily as powder. After mixing the mixture of the ice and bentonite is put into a flexible container and stored at room temperature outside the freezing facility for defrosting. The water content adjustment of the bentonite is finished when the powdered ice melts completely. In the freeze mixing method, water does not interact as liquid with the bentonite during mixing. Therefore, a simple mixer is sufficient for the freeze mixing method, whereas a very powerful mixer has to be used in the conventional method of water content adjustment.

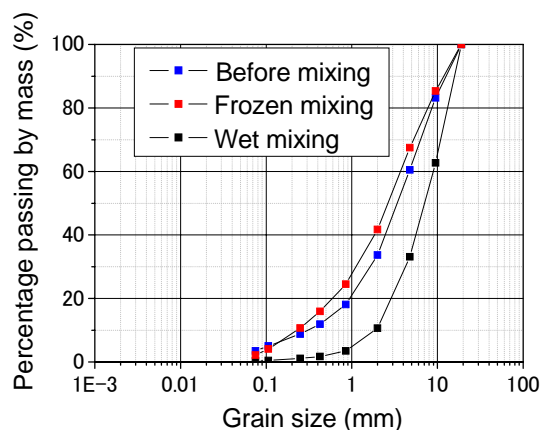


**Fig. 6 Procedure for freeze mixing method**

In the freeze mixing method, grain size distribution remains almost unchanged before and after adjusting the water content and the resulting variation in water content is smaller than that in the conventional method. Unlike the conventional method, the freeze mixing method allows adjustment of water content to high levels because the material is mixed as powder. Furthermore, because the material does not adhere to the mixer in the freeze mixing method, the weight ratio of material recovered to the material supplied before mixing is nearly 100%, compared with about 70% to 90% in the conventional method. Moreover, the load on the mixer is very light in the freeze mixing method.



**Photo 1** Bentonite materials after water content adjustment using freeze mixing method



**Fig. 7** Grain size distribution before and after water content adjustment

### EXPERIMENT OF THE SHOTCLAY METHOD

To measure the density distribution of the bentonite engineered barriers constructed by the shotclay method, an experiment was conducted by using a U-shaped precast concrete gutter of 1200 mm wide, 1000 mm high, and 1500 mm deep (Photo 2). In terms of the dry density of constructed bentonite and rebound ratio, spraying conditions were determined based on the test results preliminarily obtained by using a small spray box. A rotor type sprayer and a compressor with a discharging airflow of about 18.5m<sup>3</sup>/min were also adopted based on the preliminary investigation. Numerical targets to evaluate the quality and construction efficiency are shown in Table 1.



**Photo 2** Full scale shotclay construction experiment

Table 1 Numerical target of shotclay method

	Evaluation indicator	Value	Note
Quality	Average of dry density	1.6 Mg/m <sup>3</sup> or more	Corresponding to permeability coefficient of 1 x 10 <sup>-12</sup> m/s or less.
Construction Efficiency	Rebound ratio	30% or less	Estimation standard for shotcreting by Ministry of Land, Infrastructure and Transport

Fig. 8 shows the relationship between the dry density and water content of bentonite engineered barriers constructed by the in-situ compaction method using a vibration roller and the shotclay method. The results of the in-situ compaction method are quoted from Yoshikoshi et al. (2006), and the results of the shotclay method were obtained from the test using the U-shaped gutter (Photo 2). The density is more homogeneous in the bentonite engineered barrier constructed by the shotclay method than that constructed by the in-situ compaction method (Figure 9). The

density distributions mostly satisfy the criteria given in Table 1. About 3000 kg of bentonite base material was needed to construct a bentonite engineered barrier that completely filled the U-shaped gutter, and no clogging occurred during spraying when the freeze mixing method was adopted

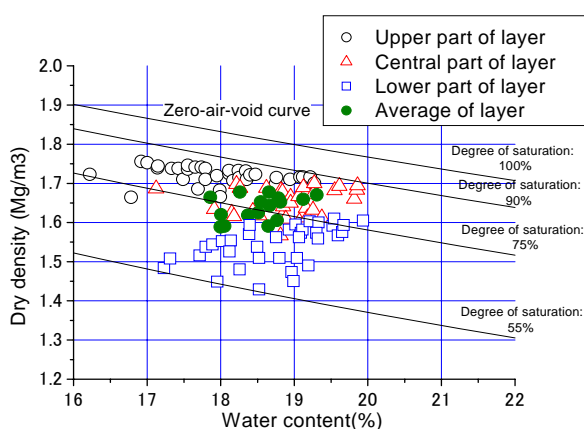


Photo 1 Bentonite materials after water content adjustment using freeze mixing method

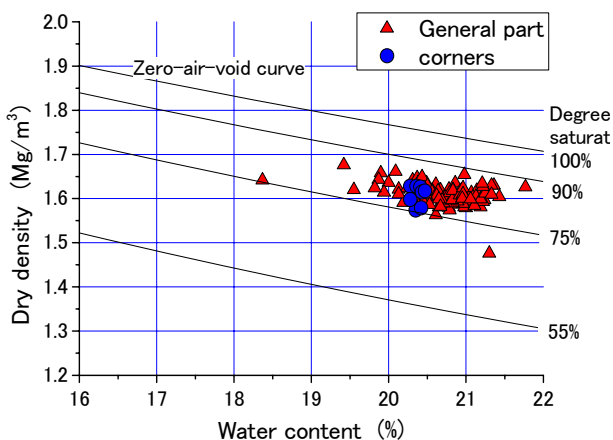


Fig. 7 Grain size distribution before and after water content adjustment

## CONCLUSIONS

The shotclay method was developed to improve the performance of the bentonite engineered barrier in a radioactive waste disposal facility. The result of the experiment attained the numerical targets to evaluate the quality and construction efficiency, and it verified the fundamental applicability of the shotclay method. Moreover, the result of the experiment showed that the method could construct more homogeneous bentonite engineered barrier than other methods, such as the in situ compaction method using a vibration roller. If such homogeneous buffer materials can be built up in the actual disposal facilities, we can expect the prescribed permeability just after construction and may leave out the further investigation on the continuous space between buffer materials and surrounding rock mass or in the between buffer materials (i.e. blocks, pellets) which possibly becomes a ground water channel. Thus, the technique of the shotclay method may simplify the procedure of the quality evaluation methods for geological disposal especially in terms of permeability or swelling pressure on saturation process of bentonite material.

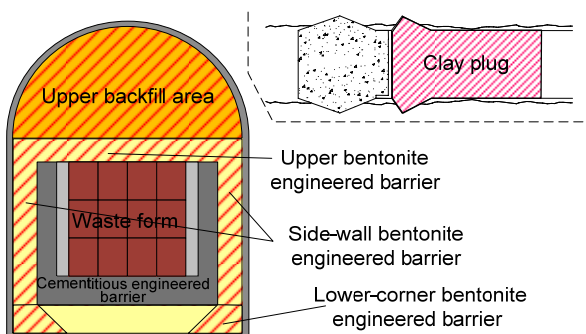


Fig. 8 Applicable area of the shotclay method

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