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## Physico-Hydro-Mechanical Properties of a Commercial Bentonite in Indonesia

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**Keywords:** Bentonite; Barrier; Water retention; Hydro-mechanical properties; Chilled-mirror hygrometer technique

**Abstract.** This paper presents the physico-hydro-mechanical properties of a commercial bentonite in Indonesia related to the possibility of its use as a barrier in the waste repository. Physical properties include specific gravity, Atterberg limits, grain distribution, and compaction. Methods used to determine physical properties followed ASTM standards procedures. X-ray diffraction (XRD) and Environmental Scanning Electron Microscopy Test (ESEM) were also utilized in order to investigate the mineral content and microscopic level of the bentonite, respectively. The hydraulics properties of the bentonite (i.e., permeability and water retention) were obtained from permeability test and chilled-mirror hygrometer test, respectively. The mechanical property of the material includes the shear strength which was determined by using direct shear tests, respectively. The results are compared to other bentonites that have been widely used in the world.

### Introduction

Bentonite is a highly plastic clay which contains large quantity of montmorillonite (or smectites) and expands when it is in contact with water in liquid form or in vapor form. In Indonesia, bentonite is often used in slurry form to solve problems in the construction of borings or excavating trenches in water-saturated soils. In fact, bentonite is now widely used as a barrier in domestic or hazardous waste repository. The bentonite or mixtures of bentonite with other materials such as sand and clay is compacted to reach a certain density. In the field, this material is directly incontact with waste, water and/or leachate. These lead to extend the characterisation of bentonite not only the consistency but also its hydro-mechanical properties.

This paper presents the physico-hydro-mechanical properties of a commercial bentonite in Indonesia related to the possibility of its use as a barrier in the waste repository.

### Material Used and Method

The material used is widely used bentonite in Indonesia. Although it has long been used for example in the drilling process, the physical, chemical, mechanical, and hydraulics properties of the bentonite has not been published yet.

The methods used to obtain the physical, chemical, mechanical, and hydraulic are related to the use of the bentonite as a barrier material. Specific gravity, the limits of Atterberg, grain size distribution, and compaction tests have been performed based on ASTM D854, ASTM D4318-93, ASTM D422-63 and ASTM D698 [1], respectively. Cation exchange capacity was determined by using saturation method with BaCl<sub>2</sub>. X-ray diffraction (XRD) method was used to determined mineral content of the bentonite. Bentonite hydraulic properties (i.e., permeability and water retention behavior) were obtained by using the ASTM D 5856-95 method [1] and the chilled mirror hygrometer technique, respectively. Chilled-mirror hygrometer technique has been used to

determine total suction of soils [2]. The chilled-mirror hygrometer is known as the most accurate technique for measuring the relative humidity [3, 4]. Mechanical property was conducted using direct shear ASTM D 3080 [1]. In the permeability and direct shear strength tests, the samples were prepared and tested at optimum moisture content and maximum dry density based on Proctor compaction test results.

## Result and Discussion

Table 1 summarizes the physico-chemical properties of bentonite performed using ASTM standards (i.e., specific gravity, Atterberg limits, grain size distribution, and compaction), and saturation method (i.e., CEC). As shown in Table 1, the bentonite has specific gravity of 2.78, liquid limit of 140%, and plastic limit of 55%. The plasticity index calculated from the liquid and plastic limits is 85%. Based on grain size distribution result, the bentonite contains 100% fine grain with 70% clay content. The maximum dry density and optimum water content of the bentonite resulted from Proctor compaction are  $1.2 \text{ Mg/m}^3$  and 23%, respectively. The bentonite has CEC of 26.8 meq/100g.

Table 1. Summary of the bentonite characteristics used in this study

Properties	Value
Specific gravity	2.78
Liquid limit (%)	140
Plastic limit (%)	55
Plasticity index (%)	85
Clay content (%)	70
Fine content (%)	100
Maximum dry density ( $\text{Mg/m}^3$ )	1.2
Optimum water content (%)	23
Cation exchange capacity (meq/100g)	26.8

Fig. 1 shows XRD result of bentonite. The figure reveals presence of montmorillonite in the bentonite and other minerals such as illite and quartz.

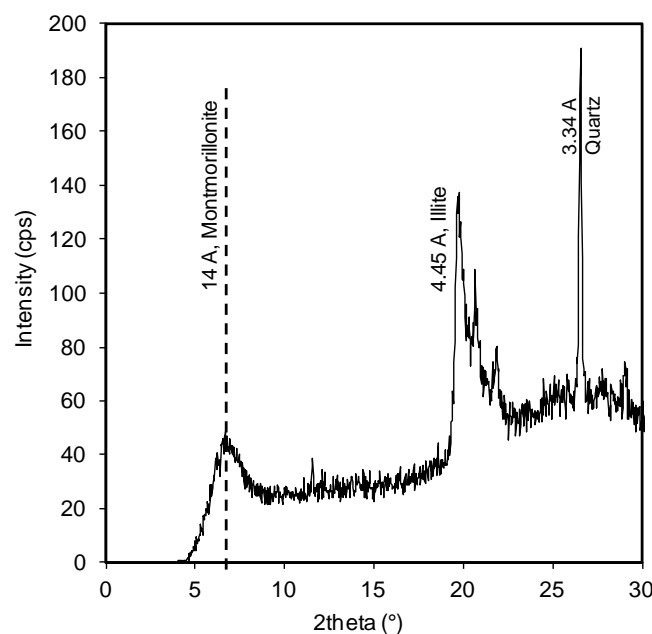


Fig. 1. XRD result of the bentonite

Environmental scanning electron microscopy (ESEM) was used to study the microscopic bentonite. Tests were carried out in the Laboratory of Chemistry at Ruhr-Universitaet Bochum, Germany. Microscopic structure is important for further investigation when the bentonite is compacted or mixed with other materials such as sand, cement, polymer [5], etc. Fig. 2 shows photos of bentonite obtained by using ESEM with magnification of 5000-50000 times. The photos show that the bentonite is composed of fine particles with a size less than  $4\mu\text{m}$  (Figs. 2a and 2b). The particles form a larger structure called aggregates (Figs. 2c and 2d). The presence of particles and aggregates of different sizes produces different sizes pores (i.e., space between them) [6, 7].

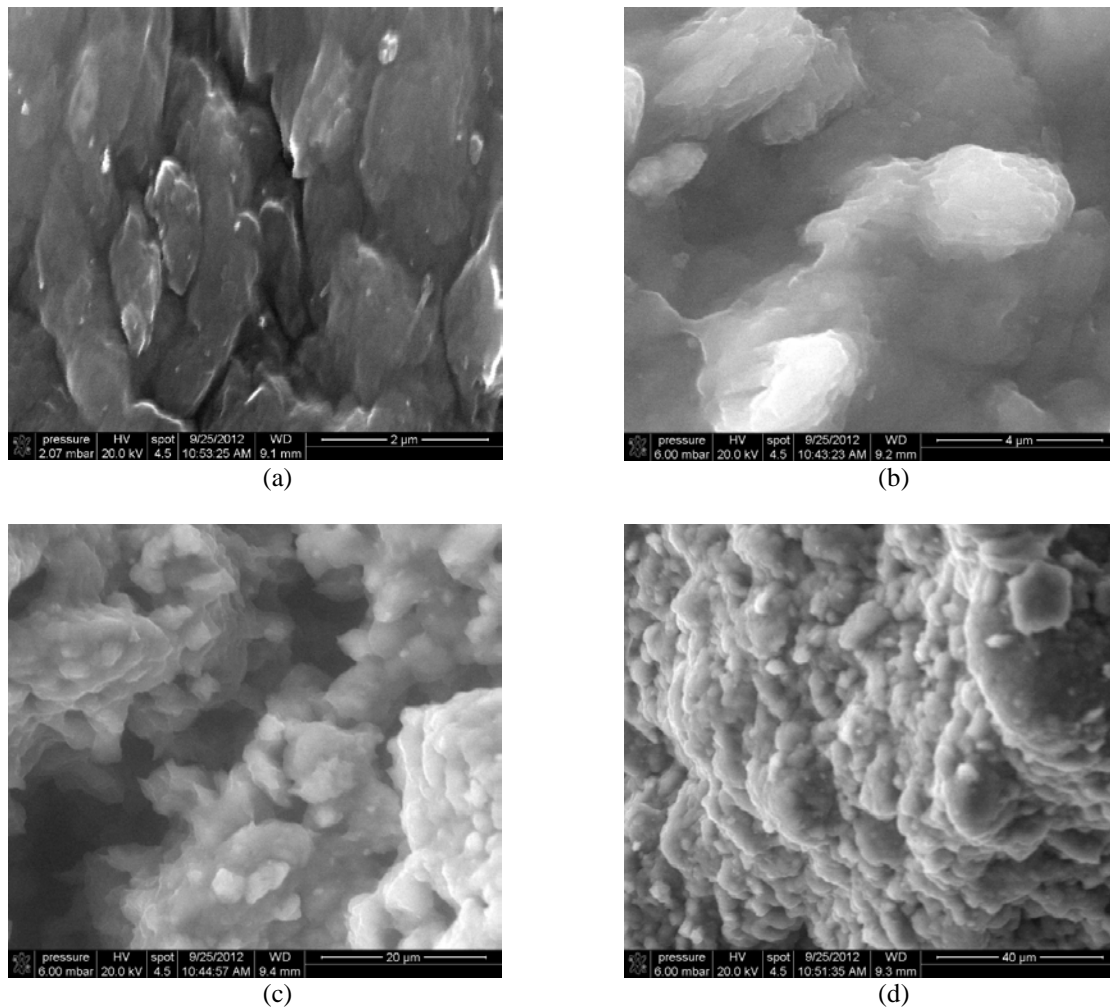


Fig. 2. ESEM photos of the bentonite

Table 2 summarizes the physico-chemical data of bentonite obtained in this study and collected from literatures for different types of bentonite. All bentonites presented in Table 2 are commercial bentonite from different countries such as Germany, India, Spain, USA, Japan, and China. Based on Unified Soil Classification System (USCS), all soils in Table 2 are highly plastic clays.

As shown in Table 2, the specific gravity of the bentonite is close to that of other bentonites. The Liquid limit and Plasticity index are less than that of other bentonites except FEBEX. The plastic limit is close to plastic limit of Calsigel, FEBEX, and MX80. For CEC, the bentonite used in this study has the lowest value. However, the physical and mechanical properties of montmorillonite soils such as liquid limit and swelling potential were not influenced by the total CEC of the soils other than only by the amount of exchangeable sodium cation in the CEC [8].

There is no unique relationship observed from data in Table 2. This is due to the variation of the physico-chemical properties and mineralogy of the bentonite. Two important parameters that

influence behavior of the bentonite (i.e., montmorillonite content and specific surface area) are not available and will be performed in the next investigation.

Table 2. Bentonite characteristics used in the world

Properties	Bentonite (in this study)	Calsigel [2]	Indian Bentonite [2]	FEBEX [9]	MX80 [10]	Kunigel [11]	GMZ [12]
Specific gravity	2.78	2.8	2.85	2.7	2.76	2.79	2.71
Liquid limit (%)	140	180	400	102	411±10	473.9	276
Plastic limit (%)	55	56	34	53	47	26.6	37
Plasticity Index	85	124	366	49	364±10	447.3	239
Montmorillonite content (%)	-	50-60 <sup>‡</sup>	-	92	75	48	
Clay content (%)	70	40	83	68	77.6	64.8	60
Fine content (%)	100	100	100	92	92.6	-	98
Total S <sub>s</sub> (m <sup>2</sup> /g)	-	500	400	725	562	388.8	420
CEC (meq/100g)	26.8	49	62	102	73	76	68
Country	Indonesia	Germany	India	Spain	USA	Japan	China

### Shear Strength of Bentonite

Direct shear test was performed on the sample at maximum dry density and optimum water content as shown in Table 1. The mechanical properties tested herein involved the determination of shear strength parameters (i.e., cohesion (c') and internal friction angle (ϕ')). The values of cohesion (c) and internal friction angle (ϕ) are 30 kPa and 20°, respectively. The result shows typical values of shear strength of clay soil. Comparison with other bentonite cannot be done due to lack of data of shear strength similar to that done here.

### Hydraulic Properties of Bentonite

The hydraulic property of bentonite that is very important pertaining to its use as barrier is coefficient of permeability. Permeability test was conducted on samples at maximum dry density of 1.2 Mg/m<sup>3</sup> and optimum water content of 23%. The coefficient of permeability obtained is 1.90×10<sup>-8</sup>cm/s or 1.90×10<sup>-10</sup>m/sec.

Comparison of permeability is made by plotting the coefficient of permeability value versus dry density of sample. Fig. 3 shows permeability of bentonite used in this study and several compacted bentonite obtained from literature plotted in semi-log scale as a function of bentonite dry density. According to the figure, the permeability of the bentonite used is relatively higher than that of other bentonites. The low permeability of other bentonites may be attributed the high percentage of monmorillonite. More data of the bentonite based material are required to give better comparison.

Besides permeability, the relationship between the water content and the negative pore water pressure (or suction) also plays important role in hydraulics behavior. The relationship also called water retention curve shows the bentonite ability to hold water by increasing or decreasing of suction. In this study, the negative pore water pressure is determined using a chilled-mirror hygrometer technique called AQUALAB. The tests were conducted at the Soil Mechanics Laboratory, Ruhr-Universitaet Bochum, Germany. Fig. 4 shows the relationship curve between water content and suction of bentonite used in this study compared with bentonites that are commonly used in the world i.e., MX80 (USA) and Calcigel (Germany). As shown in the picture, the curve of the bentonite used is placed in between that of Calcigel and MX80. It shows that the

ability of bentonite used in this study to retain water is higher than that of Calsigel that is proposed to be a sealing material for high level waste in Germany.

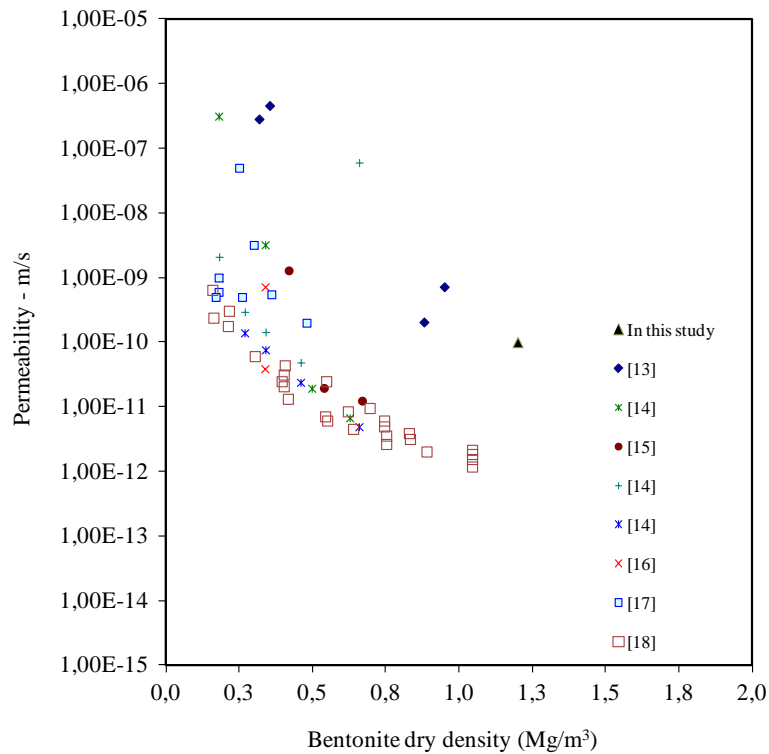


Fig. 3. Permeability of compacted bentonite as a function of bentonite dry density

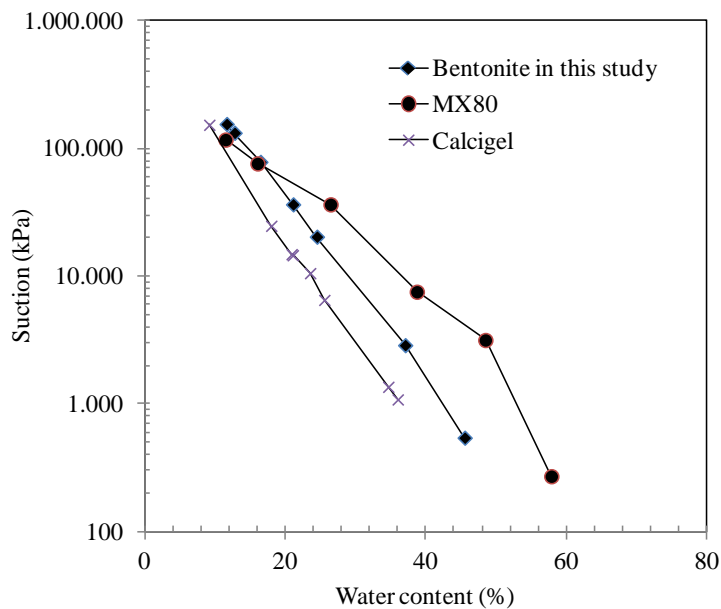


Fig. 4. Water retention curves of bentonite

### Conclusion

A study on the physico-hydro-mechanical properties of a commercial bentonite in Indonesia has been presented. The results obtained show that: (1) Bentonite is used has a specific gravity of 2.78 with initial moisture content of 14.94%. Liquid limit, plastic limit, and plasticity index are 140%, 55%, and 85%, respectively. Presence of montmorillonite was confirmed in XRD result; (2) Bentonite has cation exchange capacity of 26.8 meq/100g. Compared to bentonite commonly used in the world, the value is small but it is still much higher than that of clays generally; (3) From the



hydraulic properties, the permeability of the compacted bentonite at maximum density is  $1.9 \times 10^{-10}$  m/sec. In addition, the bentonite is also able to retain water with a very large capacity and comparable to bentonites that are currently widely used in Europe and America. The shear strength parameters (i.e., cohesion and internal friction angle) obtained at the same condition as permeability test are 30 kPa and  $20^\circ$ , respectively.

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