Compaction Parameters of a Chitosan-Bentonite-Sand Mixture

Nada Salsabila[1], Yulian Firmana Arifin[1,2], Ade Yuniati Pratiwi[3]

y.arifin@ulm.ac.id[1]

Wetland-Based Materials Research Center, University of Lambung Mangkurat, Indonesia[1]
Civil Engineering Bachelor and Master Program, University of Lambung Mangkurat, Indonesia[2]
Civil Engineering Study Program, Ujung Pandang State Polytechnic, Indonesia[3]

Abstract. The water content and energy applied during the compaction process affect the behavior of soils, particularly those containing clay. This also includes material mixtures such as polymer-enhanced bentonite-sand mixtures. The aim of this research is to carry out compaction tests and obtain parameters for the chitosan-bentonite-sand mixture material. The materials used are chitosan polymer, bentonite, and sand. The type of bentonite is calcium bentonite. Sand was taken from the Barito River, which is a common material used in construction and is available in large quantities. The two materials, chitosan and bentonite, are chemically mixed first, with a composition of 2% and 98% on a weight basis, respectively. This mixture was then added to sand with a composition of 10% chitosan-bentonite and 90% sand. Standard and elevated Proctor compaction tests were applied to the samples. The results showed the maximum dry density (MDD) and optimum moisture content (OMC) of standard Proctor compaction are 17.6 kN/m^3 and 9.9%, respectively. The cohesion (c) and internal friction angle (ϕ) obtained at the density are 7.79 kPa and 26.68°, with a permeability (k) of 1.437×10^{-11} m/s. For samples compacted using an elevated standard Proctor, MDD and OMC obtained are 17.7 kN/m^3 and 5.89%, respectively. Other parameters are c of 9.11 kPa, ϕ of 23.03°, and k of 1.432×10^{-11} m/s.

Keywords: Proctor compaction, chitosan, polymer, bentonite, dry density.

1 Introduction

The amount of waste continues to increase along with the increase in population. With the increasing amount of waste, this creates new problems, so efforts need to be made to repair and increase the performance of final disposal sites. Landfills should have clay liners to prevent leachate (i.e., liquid from rainwater exposure in landfills) from contaminating groundwater. It is hoped that the base coating will prevent leachate seepage into the surrounding area.

Bentonite is a natural clay with a fine, soft powder texture. This soil is often recommended for use as a clay liner. However, because of its very expansive nature, this soil is usually mixed with sand or soil around the landfill with a certain percentage [1,2]. The percentage of bentonite obtained is at least 25% of the dry weight of the mixture for those using sand [1] and 10% for those using claystone mixtures [3]. This percentage really depends on the permeability of the compacted soil mixture. The permeability that meets the requirements is a maximum of 1×10^{-9} m/s [4,3].

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A bentonite percentage that is too high, up to 25%, is still not profitable in terms of the cost and mechanical properties of the mixed soil. Therefore, efforts are made to reduce the percentage of bentonite by adding other materials, such as polymers. The addition of 0.2% polymer can reduce the amount of bentonite to only 10% when mixed with sand [5–7]. Its reliability in long-term field applications has also been tested [5, 7]. However, the polymer used is a synthetic polymer.

Natural polymers can also be used as suggested in previous research, for example, chitosan [8, 9]. Chitosan is a natural polymer made from shrimp shells and other crustaceans. stated that a bentonite-chitosan mixture with a density of 1.6 gr/cm3 and a water content of 10% obtained a permeability coefficient that became smaller with increasing chitosan content. All samples with chitosan percentages of 2%, 4%, and 6% met the permeability requirements (i.e., the coefficient values were not too different). So a 2% chitosan sample is quite effective if used for the clay liner layer in landfills. However, this research still did not use sand. In addition, the maximum density and optimum water content used in the study have not been investigated. Therefore, it is necessary to carry out compaction tests using both standard Proctor and an elevated energy Proctor mixture of bentonite, chitosan, and sand.

This research aims to carry out a compaction test of a mixture of bentonite, chitosan, and sand to obtain the maximum density (maximum dry density) and optimum water content of the mixture. This test is carried out in the laboratory, and other important parameters are also tested, such as shear strength and permeability.

2 Material used and method

This research uses commercial bentonite, which is easy to buy on the market. The type of bentonite used is the same material as previous research, namely calcium bentonite [8]. Bentonite has a specific gravity of 2.71 with a liquid limit, plastic limit, and shrinkage limit of 351.71, 44.68, and 41.89%, respectively. This results in a high plasticity index of 307.03%. Meanwhile, the sand used is Barito River sand, with a composition of 0.71% gravel, 10.68% coarse sand, 63.59% medium sand, 23.16% fine sand, and 1.87% clay. The chitosan used is also a commercial material available on the market. Chitosan in powder has a particle size of 100–300 mesh, a water content of 8.5%, a residue of ignition of 0.5%, a viscosity of 50 cps, and a degree of deacetylation of 94%.

Sample preparation

Sample preparation was carried out in two stages, namely mixing bentonite and chitosan and adding sand. The process of mixing bentonite and chitosan was carried out based on the procedure suggested by Hidayat & Arifin [8]. and Taytak et al. [10]. 2 g of chitosan was mixed with an acidic solution with a concentration of 2% (v/v). 98 g of bentonite was added to obtain a mixture of 2% chitosan and 98% bentonite and stirred for two hours. 100 ml of sodium tripoyposphate (5 wt%) was added and stirred for 4 hours. The mixture was filtered, washed with distilled water until pH 7, and dried at 60 °C.The mixing was carried out several times until the bentonite and chitosan sample requirements were met. In order to produce one compaction sample, a mixture of bentonite and chitosan weighing 250g is required. This mixture is subsequently mixed with 2250g of sand at proportions of 10% and 90%, respectively. This composition follows the percentage of polymer-enhanced bentonite-sand mixture material that has been marketed commercially (Trisoplast). To determine the functional groups of the chitosan-bentonite mixture, Fourier transform infrared (FTIR) testing was carried out [11–13].

Testing of the chitosan, bentonite, and sand mixture

The chitosan-bentonite-sand mixture was tested for compaction with two different energies, namely Proctor Standard compaction [14] and an elevated energy of Proctor. An elevated energy uses the same mold size as the standard one, with a number of layers of 5 and a hammer weight of 10 lb. From these two methods, each curve is obtained to obtain maximum dry density and optimum water content. These two parameters (dry density and optimum water content) are used to create samples to be tested for permeability and shear strength. The permeability and shear strength methods used are the falling head test [15–18] and the direct shear test [19].

3 Results and discussions

Functional groups of chitosan, bentonite, and a mixture of bentonite and chitosan

Figure 1 shows the FTIR result curve for chitosan, bentonite, and a bentonite-chitosan mixture of materials. As seen in Figure 1, the peak of the curve for chitosan is located at wave numbers of 993.09, 1322.04, 1410.04, 1585.88, 2885.88, and 3240.22 cm^{-1}. Meanwhile, for bentonite, the peak is located at wave numbers 691.09, 792.41, 995.97, 1227.25, 1415.92, 1555.80, 1633.47, 3401.11, and 3625.51 cm^{-1}. For the bentonite-chitosan mixture, the peak of the FTIR curve is located at wave numbers of 836.63, 913.71, 1003.38, 1112.55, 1416.82, 1553.72, 1632.13, and 3364.18 cm^{-1}. Based on these data, it is clear that significant changes in the bentonite-chitosan mixture are at wave numbers 3291–3361 as a result of N-H and OH stretching [20].

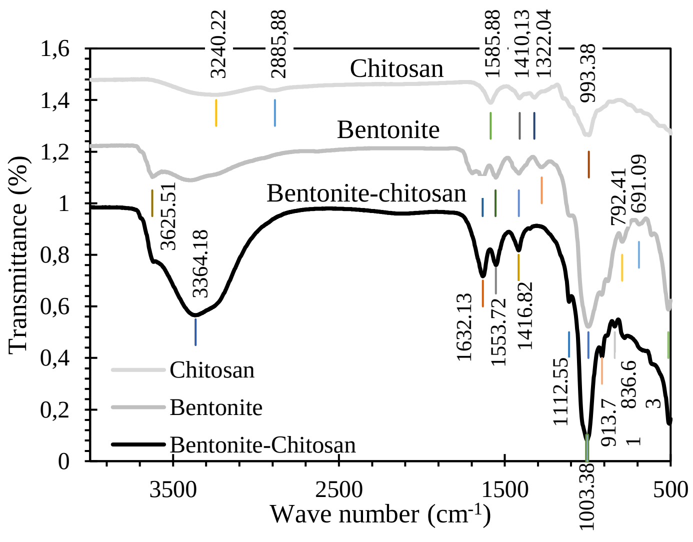

Fig 1. FTIR spectra of chitosan, bentonite, and a bentonite-chitosan mixture

Compaction tests

Figure 2 shows the standard Proctor compaction test curve and an elevated energy of Proctor plotted in dry density as a function of compaction water content. As seen in the figure, each curve produces data on maximum dry density and optimum water content, as summarized in Table 1. The table also provides information regarding the characteristics of the two types of compaction. The results show that the maximum dry density and optimum moisture content of the compacted Proctor standard are 17.6 kN/m^3 and 9.99%, respectively. And the results of elevated Proctor compaction are a maximum dry density of 17.6 kN/m^3 and an optimum moisture content of 5.89%. Even though the energy provided in Type 2 compaction is higher, the maximum dry density obtained is not much different. This is due to the dominant sand content in the mixture, which results in a tendency for an irregular shape of compaction curve, especially at low water content [21].

These data can be used as a basis for implementation in the field to obtain a value of 90% maximum dry density. In this research, the maximum dry density and optimum water content data were used as the density and water content of the next test sample, namely the falling head test to obtain the permeability coefficient and the direct shear test.

Table 1. Characteristics of compactions and the result

	Proctor standard (Type 1)	Elevated Proctor (Type 2)
Number of layers	3	5
Volume of mold (cm^3)	944	944
Number of drop per layer	25	25
Height of drop (mm)	304.8	450
Weight of hammer (lb)	5.5	10
Optimum moisture content (%)	9.99%	5.89
Maximum dry density (kN/m^3)	17.6	17.7

Direct shear tests

From the direct shear test, two components of soil shear strength were obtained, namely cohesion (c) and internal friction angle (ϕ). The test results of the two compaction conditions, namely Type 1 and Type 2, are summarized in Table 2. It can be seen in the table that type 1 compaction with a maximum dry density of 17.6 kN/m^3 and a water content of 9.99% obtained c and ϕ of 7.79 kPa and 26.68° respectively. And, for Type 2 compaction, c and ϕ are 9.11 kPa and 23.03° respectively. These results show that samples with higher density and lower water content (Type 2) produce higher cohesion as a result of the higher density of the chitosan and bentonite mixture. Besides that, at low water content, the attractive force of clay particles becomes high which results in the bonds between particles and ultimately the cohesion obtained being higher than at higher water content (Type 1). Meanwhile, the internal friction angle obtained is the opposite, where samples compacted using Type 1 compaction with a higher water content produce a higher internal friction angle as a result of the reduced cohesion value at high water content. This causes internal friction between sand to become dominant. The cohesion and internal friction angle were found to be lower when compared to Trisoplast with cohesion of 20–27.7 kPa and ϕ of 36.1º–40.7º. Sand gradations that tend to be uniform used in this study result in pores that tend to be large and produce smaller shear strengths.

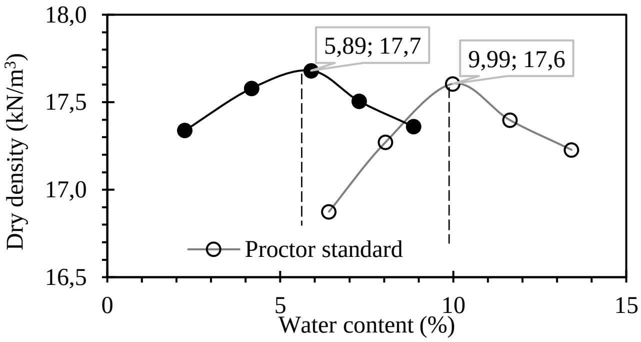

Fig 2. Compaction curves of compacted bentonite-chitosan-sand mixture

Table 2. Direct shear test results

Parameters	Compaction Type 1	Compaction Type 2
Optimum moisture content (%)	9.99	5.89
Maximum dry density (kN/m^3)	17.6	17.7
Cohesion (kPa)	7.79	9.11
Internal frictin angle (º)	26.68	23.03

Permeability test

During permeability testing to obtain the permeability coefficient, observations are carried out for a long time to produce the smallest change in permeability. The results of observations and calculations of permeability coefficients of samples are summarized in Table 3. Based on Table 3, the time required to obtain the results of one permeability test using the falling head test method is 388,800 s or 4.5 days. From the data it can be seen that the permeability coefficient of the bentonite-chitosan-sand mixture of samples compacted with Type 1 and 2 each produces a permeability of 1.44×10^{-11} m/s and Type 2 1.43×10^{-11} m/s. These results show that Type 1 and 2 samples which have almost the same density even though the water content is different produce almost the same permeability. This data is then plotted in a graph of the relationship between time and permeability as shown in Figure 3.

As shown in Figure 3, the two permeability curves as a function of time for the two samples look almost the same. Although Type 1 samples have higher water content, which generally results in lower permeability, this was not observed in this study. This result is in accordance with the results of previous research that the water content of the sample has no effect on the properties of the bentonite-polymer-sand mixture which has the same composition as this research [22].

Table 3. Results of permeability test

Time (s)	Coefficient of permeability (m/s)	
	Type 1	Type 2
28.800	4.9807×10^{-10}	4.9807×10^{-10}
57.600	5.0373×10^{-10}	5.0230×10^{-10}
86.400	4.4552×10^{-10}	3.8050×10^{-10}
172.800	1.0700×10^{-10}	1.0653×10^{-10}
259.200	4.3018×10^{-11}	6.4292×10^{-11}
388.800	1.43706×10^{-11}	1.4329×10^{-11}

In general, the permeability of the two samples meets the material requirements as a clay liner, namely the permeability coefficient is smaller than 1×10^{-9} m/s, which is a requirement generally accepted in the world [23]. Based on Minister of Public Works Regulation No. 3 of 2003, for clay liners in Indonesia requires a higher value, namely 1×10^{-8} m/s [24]. It can be seen that density affects the permeability coefficient value, namely the higher the density value, the lower the permeability coefficient value will be. This is due to the shrinking of the soil pores after compaction.

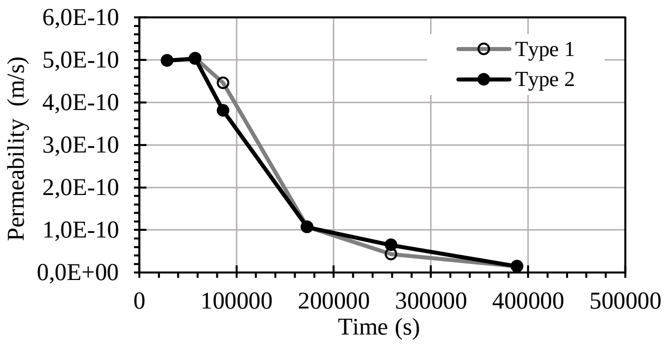

Fig 3. Permeability of bentonite-chitosan-sand mixture as a function of time

A comparison of the permeability coefficient of the bentonite-chitosan-sand mixture with others is shown in Figure 4. The comparison materials are materials commonly used as barriers in landfills, namely bantonite-sand mixtures [25], polymer-enhanced bentonite-sand mixtures (Trisoplast) [26]. , and chitosan-bentonite [8]. Permeability tests on bentonite-sand mixture samples (90/10 ratio) without chitosan were also carried out. It was found that without chitosan, the permeability of the bentonite-sand mixture was 2×10^{-9} m/s. This value is greater than the requirement (i.e., 1×10^{-9} m/s). Meanwhile, the permeability of the bentonite-chitosan-sand tested in this study is close to that of the commonly used commercial material (Trisoplast). With a bentonite percentage of only 10%, this material is quite efficient when seen by the permeability value it produces.

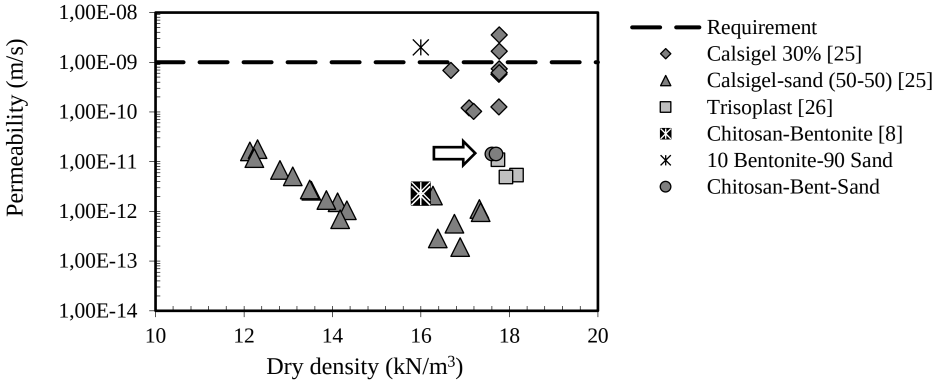

Fig 4. Coefficient of permeability as a function of dry density

4 Conclusions

Several parameters of the bentonite-chitosan-sand mixture with compositions of 9.8%, 0.2%, and 90% on a dry weight basis were obtained in this study. In the compaction test, the maximum dry density and optimum moisture content of samples compacted using the Proctor standard were 17.6 kN/m^3 and 9.99%, respectively. Meanwhile, when compacted using an elevated standard Proctor, a maximum dry density of 17.7 kN/m^3 and an optimum water content of 5.89% were obtained. The shear strength parameters obtained from the direct shear test are respectively cohesion of 7.79 kPa and ϕ 26.68° for samples compacted with the Proctor standard. Meanwhile, when compacted with an elevated energy of Proctor, cohesion of 9.11 kPa was obtained and the permeability coefficient of samples compacted with two types of compaction was respectively 1.437×10^{-11} m/s and 1.432×10^{-11} m/s for Type 1 and Type 2. Both samples meet the requirements as a clay liner, both those generally applicable in the world (i.e., 1×10^{-9} m/s) and those in Indonesia (i.e., 1×10^{-8} m/s).

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