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Full Length Research Paper

Usability of sand-bentonite-cement mixture in the construction of unpermeable layer

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The aim of this study is to prepare a mix that can be used in impermeable fill as an alternative to clay which can sometimes be difficult to find. In the study, bentonite and cement were chosen as admixtures and sand was chosen as the main material. The main reason for choosing bentonite and cement as admixtures is that they are impermeable and easy to find. Sand was chosen as the main material in the experiments to make use of the available sand pits at Yenicekent in Denizli, and to provide a pre-investigation for a possible future impermeable fill construction in the said region. Another reason for choosing sand as a main material was its low price. According to the result of the three mixtures tested, the mixture including 10% bentonite + 90% sand is the most economical solution that satisfies the limits values needed for clay core of earth fill dams and clay liners of solid waste storage areas.

Key words: Bentonite, cement, earthfill, sand, unpermeable layer.

INTRODUCTION

If the natural soil does not meet the requirements of the structure to be built, solutions like changing the place of the construction or removing the unsuitable soil layer are mostly not economical. For this reason, improvement of the soil properties with various admixtures is widely used in the engineering applications today as an appropriate and economical solution.

Earthfill dam which is one of the water retention structures constructed in order to attain the maximum benefit from water – the most necessary element for human survival – and solid waste storage facilities where wastes generating from human consumption are kept in safe and even from where the maximum benefit is attained are the two engineering structures in which the quality of impermeability is at the forefront. Whether there will be a waste water leakage in the storage facility or not is one of the first questions that come to mind (Akbulut, 1996)

It is known that gas and liquid formations are one of the most important causes of influence of the facility on ecological balance and groundwater quality. For this reason, impermeability mattresses are used in the design of solid waste storage facilities to block fluid leak.

Earthfill dams have become the most widely used dams since they are constructed with materials found in nature with minimum processing. Moreover, the fact that these earthfill dams can be built on various types of foundations is one of the principal reasons for choice of these dams.

Impermeability is the most important parameter in the choice of the material used in the impermeable clay core of the earthfill dams. It is not always possible to find the clay material that provides the sufficient impermeability. This study is made to design a material with low permeability that can be used instead of natural clay.

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Notations: SW, well-graded sand, γ_{kmak} , maximum dry unit weight (kN/m3); γ_s , unit weight of soil solids (kN/m3); **wopt**, optimum moisture content (%);**wL**, liquid limit (%);**qu**, unconfined compression strength (kN/m2); **k**, coefficient of permeability (cm/s); **e**, void ratio; **By**, bentonite ratio; **Çk**, cement ratio.

LITERATURE REVIEW

The interest in bentonite has increased in the recent years because of the need for impervious materials and the inadequacy of natural sources. Bentonite is the primary admixture used in the design of materials that can replace the clay used for the purpose of impermeability. In the recent years many studies have been made on bentonite and its compounds. Some papers constituting the base of this study are summarized below.

Studies on sand-bentonite mixtures are mostly focused on rate determination and variations in physical properties. Adding bentonite to the mixtures effects the compressibility property of the materials with high plasticity. In the passage from sandy state to clayey state, 2% value of bentonite ration is known as the initial value (Bowles, 1998).

The increase of bentonite displays a linear increase on liquid limit, but it has a limited effect on plastic limit (Bowles, 1998).

The most important effect of adding bentonite to soil is that the permeability of the soil decreases. This is mostly caused by the fact that as bentonite enlarges approximately ten times when it is mixed with water, it fills the cavities of coarse material (Bowles, 1998).

Wang (1984) presented correlations about the properties used in the classification of soils showing variation of permeability according to maximum dry density and optimum water content.

In the laboratory studies they carried out, Kenney et al. (1992), obtained the results that the permeability of sand-bentonite mixtures is dependent on the water content, chemistry of the system and its variations. According to Kenney et al. (1992), obtaining bentonite-sand mixtures with low permeability is dependent on the existence of adequate bentonite in the mixture and the uniform distribution of this bentonite in the mixture.

Cracks caused by drying are dependent on the water content and the amount of bentonite used in the mixture. In the mixtures with a high level of bentonite rate, the decrease of water content causes cracks in the surface (Esener, 2005)

Besides bentonite, which had been used in the studies that have been made until now, cement was also used as an admixture in this study additionally to bentonite in order to observe and evaluate its effects. The main reason for using cement is to obtain a material that can be used in the basements of stock areas like mines needing high basement pressure.

MATERIALS USED

Bentonite

Bentonite was first introduced as soap clay in 1873 by William Taylor and took its name when Fort Benton formation was found in Rock Creek site. Due to the fact that the clay mineral with the same properties was found in the Montmorillian area of France in 1874, this clay mineral was named montmorillonite. The application area and production of this new clay which has an enlarging property in water by creating a jelly mass, is increasing rapidly (Caki, 1995).

Bentonite is soft in its natural state, it disintegrates in water and gives a greasy impression when touched. It has a high potential of water retention due to its very small grains with a large surface contact area. It easily absorbs oil and glycerin.

The bentonite deposits in Turkey are formed along faults combined to crack systems and they have hydrothermal origins. The 70% of bentonite stocks of Turkey are in Çankırı region. The large bentonite deposits in the Southern Çankırı region (Hancılı, Büyükhacıköy, Küçükhacıköy), are formed along overlapping faults which are contact zones formed by old upper cretase ophyolites with upper myocen old volcanic rocks. The bentonites in northern Çankırı (Kurşunlu) are formed in various zones in the region and the bentonites in Tokat-Reşadiye, Çanakkale-Ayvacık, Kütahya-Başören, Eskişehir-Mihalıççık, Ordu-Ünye and Fatsa regions are formed according to the fault system (Magistris et al., 1998),

In the experiments with bentonite as an admixture, it was determined that the natural water content is 8% and liquid limit is 360%. The result of the investigation made by applying the X-ray scattering method, used for determining chemical combination in geotechnical engineering, is given in Table 1.

Cement

The chemical components of the P32.5 cement used in the experiments are given in Table 2. The rate of admixture is 43.62% and the clinker is 56.38%.

Sand

The dry and washed sieve test results made for determining the category of the sand with 0.92% water content brought from Yenicekent (Denizli) to be used in the experiments are given in Figure 1.

In the analysis, it was found that the category of the material does not change in both two methods and that the sand is well graded (SW) according to combined classification system.

Due the fact that the use of the sample taken from sand deposit in the natural condition would increase the cost and the amount of the admixture in the experiments, the portion passing from the 0.63 mm. sieve was used instead. While economical solution was achieved by decreasing admixture amount, the decreasing particle size will help reaching the desired permeability on the other hand. As a result of the picnometer experiment, the dependent density of the sand that would be used in the experiments was found to be 2.64.

Experiments

In the experimental studies, the sand, prepared as described in materials used is mixed with bentonite and cement at various ratios of its dry weight, and the usability of the prepared samples in impermeability aimed fillings are investigated (Önalp, 2002; Bowles, 1998) the second group mixtures are obtained by mixing cement with sand in 5 and 10% ratios and the third group mixture is obtained by mixing 10% bentonite and 5% cement with sand. Compaction test, unconfined compression test, liquid limit, consolidation and permeability tests were applied on the mixtures in the laboratory studies.

Liquid limit tests

Figure 2 shows the bentonite ratio - liquid limit relationship found after the liquid limit tests on sand bentonite mixtures containing 10,

Table 1. The chemical components of Bentonite.

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
%	58.64	15.24	3.96	4.48	2.39	3.22	1.02

Table 2. The chemical composition of P32.5 cement (Denizli cement)

Components	%
SiO_2	33.53
Al_2O_3	8.91
Fe_2O_3	4.24
CaO	40.14
MgO	1.93
SO_3	1.41
Na_2O	1.33
K_2O	2.23
Cl	0.012
Na_2O+0.658 K_2O	2.8

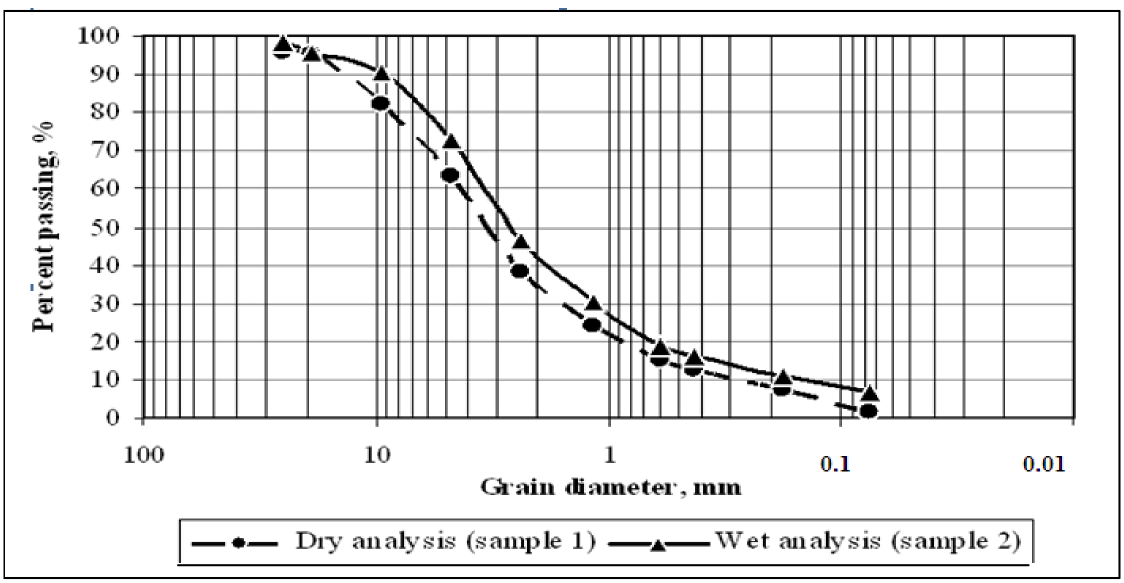

Figure 1. Comparison of Washed and Dry Sieved Samples

20, 30 and 40% bentonite. The equation of the line in Figure 2 is determined as:

$$wL = 3.374\ By + 28.395 \quad (1)$$

Compaction tests

For the purpose of obtaining the optimum water content required in order to carry on the following phases of the experiments, compaction tests were applied on sand, bentonite and all mixtures. The equation of the line on Figure 3 is:

$$By = -0.0069\ (\gamma k)max + 1.7177 \quad (2)$$

The equation of the line in Figure 4 is obtained as:

$$wopt = 0.3644\ By + 9.8026 \quad (3)$$

It was observed in the experiments that with the increase of bentonite rate while maximum dry unit weight decreases (Figure 3) the optimum water content increases (Figure 4).

In the experiments on the second group of mixtures, it was observed that the dry unit weight and optimum water content increases when the cement admixture increases (Figures 5 and 6). The equation of the line in Figure 5 is given as:

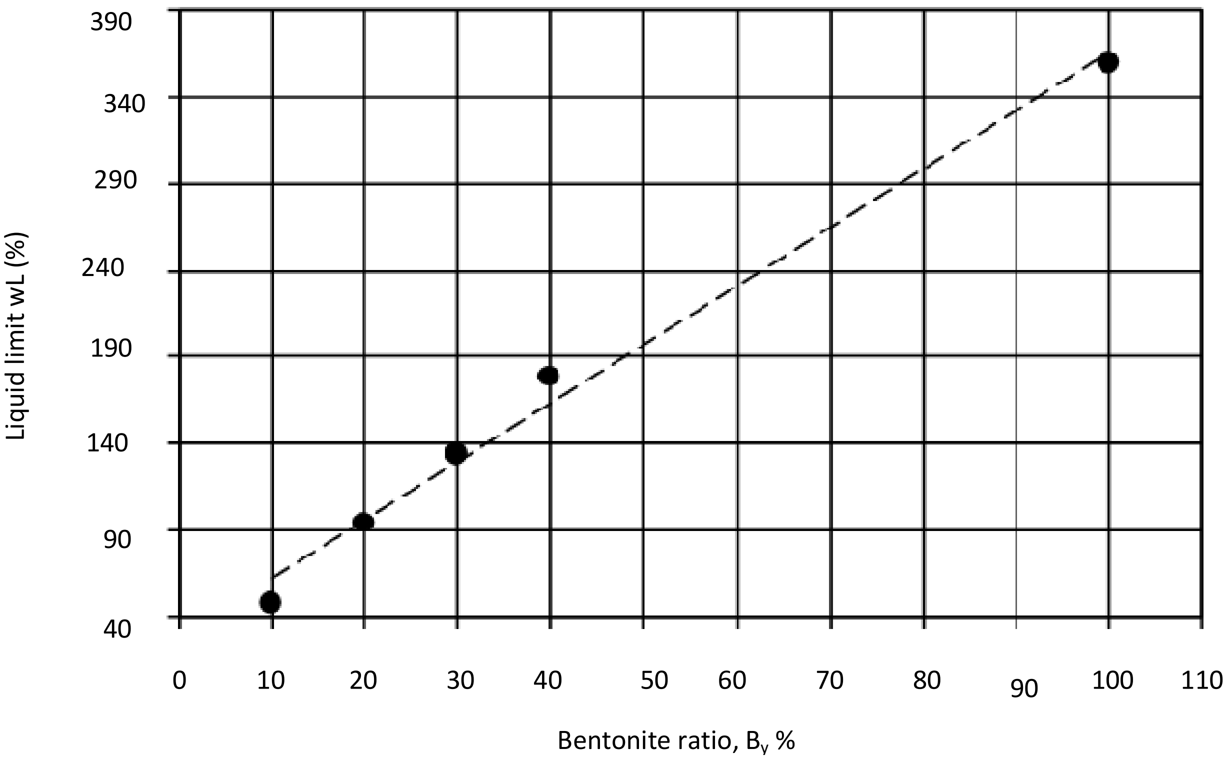

Figure 2. Bentonite % - liquid limit relationship graph.

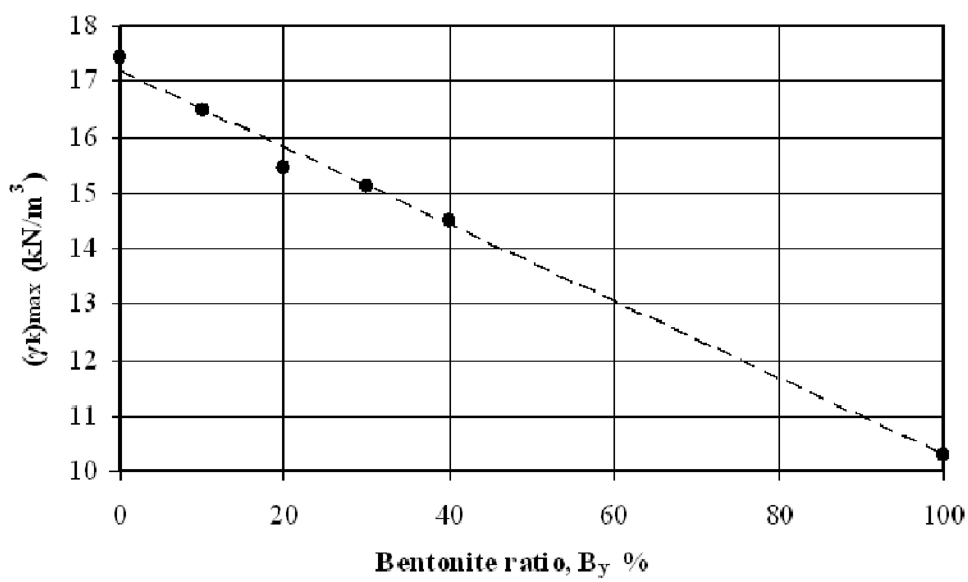

Figure 3. Variation of maximum dry unit weight with Bentonit percent.

$$(\gamma k)max = 0,003Çk + 1,7407 \quad (4)$$

The equation of the line in Figure 6 is obtained as:

$$Wopt = 0,22\ Çk + 9,75 \quad (5)$$

It was seen that the maximum dry unit weight increased very little for the 10% bentonite + 5% cement mixture when compared to 10% bentonite added mixture and that it decreased significantly when compared to 5% cement added mixture (Figure 7).

When the optimum water contents of these mixtures are analyzed, a decrease is observed for the bentonite and cement added mixture when compared to bentonite added mixture and an

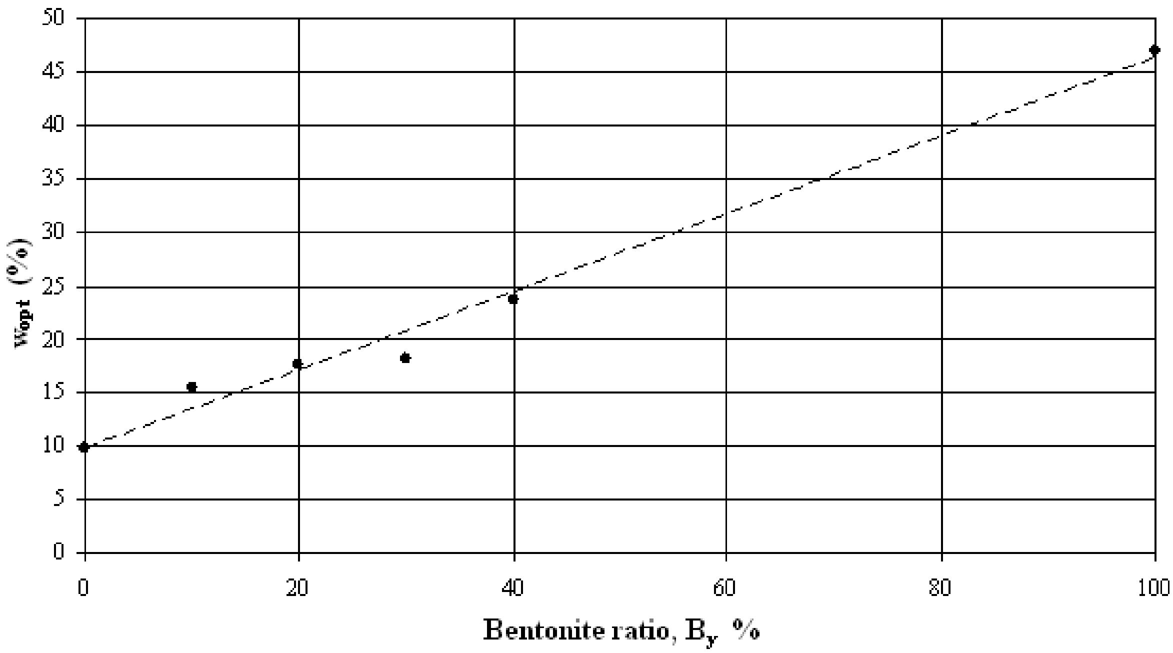

Figure 4. Variation of optimum water content with Bentonite percent.

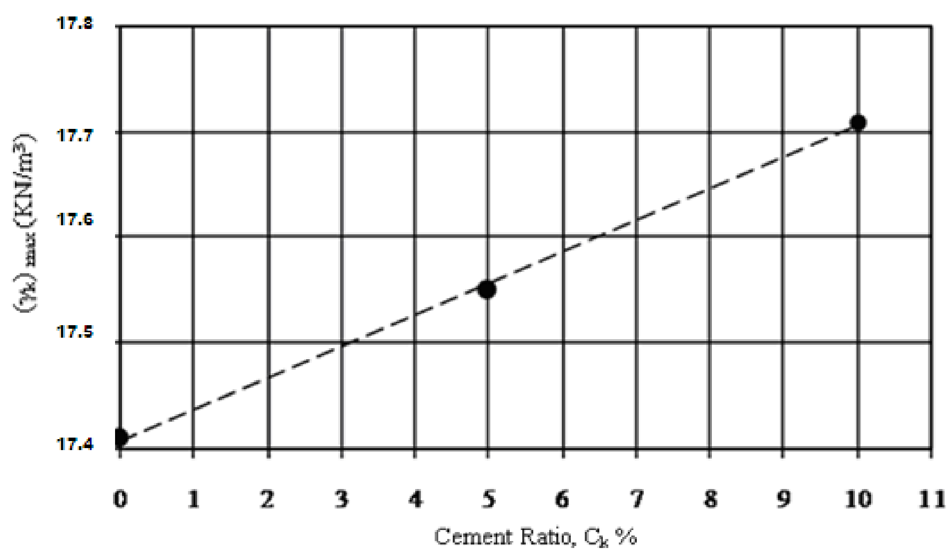

Figure 5. Variation of Maximum Dry Unit Weight with Cement Percent.

increase is observed when compared to the cement added mixture (Figure 8).

Unconfined compression test

The unconfined compression test was applied on all mixtures in three different times, immediately, one week later and 28 days later. A group of three samples was prepared for each mixture. The test was applied on the first sample group as soon as it was prepared. After wrapping with thin tensile cellophane, in order not to lose water content, the other two sample groups were kept in desiccator. When the unconfined compression strengths (qu) of bentonite added mixtures are analyzed, it shows a decrease at the end of the first week compared to the sample broken after preparation. It is observed that the qu value of sample broken on the 28th day is higher than the 1 week old sample but it is lower than the qu value of the sample broken immediately (Figure 9).

When the qu values of bentonite added mixtures are analyzed in three groups – as the broken immediately, the broken one week later and the broken 28 days later – it is determined that in each situation these values show an increase up to 20% bentonite

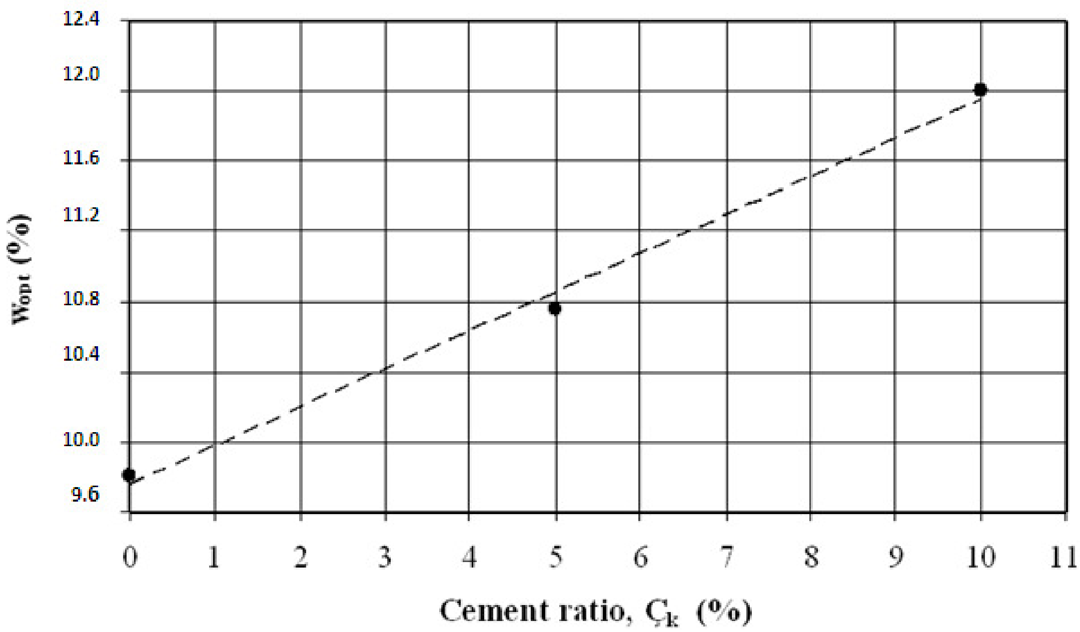

Figure 6. Variation of Optimum Water Content with Cement Percent

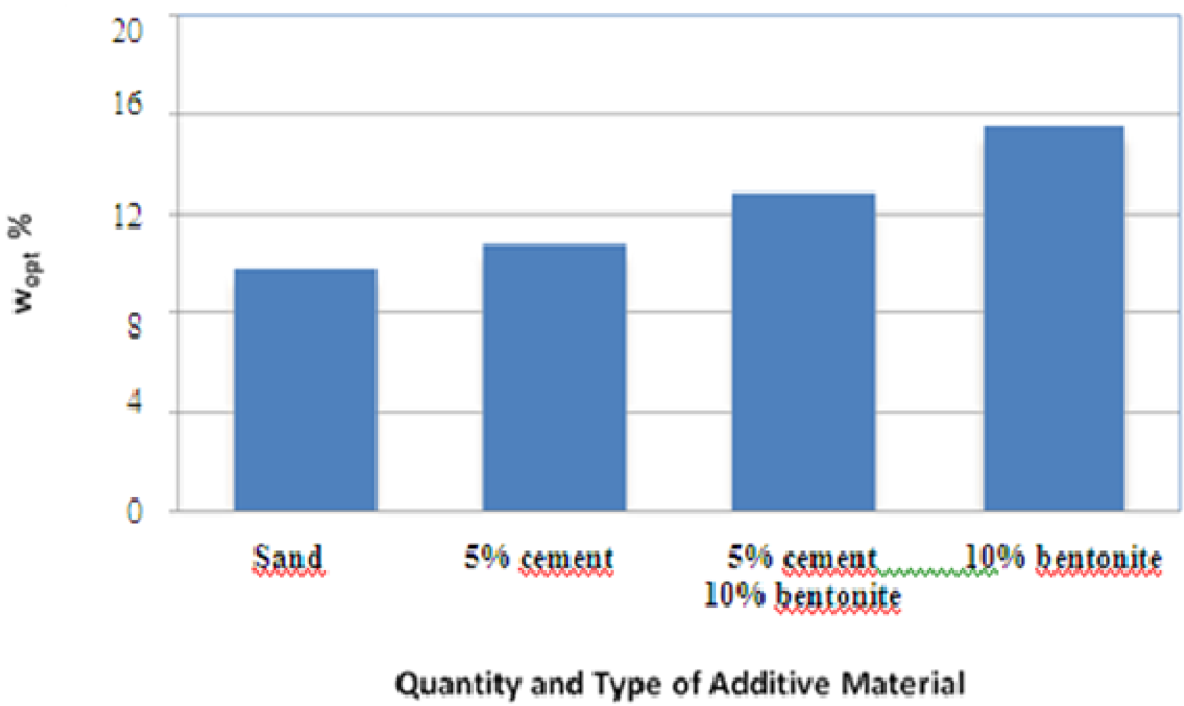

Figure 7. Variation of maximum dry unit weight with the admixture type and amount.

addition and a decrease beyond this level (Figure 10).

When the variation of qu values of 5 and 10% cement added mixtures are considered, it is observed that both of the samples show increase and both gain most of their strengths after the first week (Figure 11)

When the qu values of bentonite added mixtures are analyzed between them as the broken immediately, the broken one week later and the broken 28 days later it was seen that qu value of cement added mixtures increases with cement ratio excluding the immediately broken samples (Figure 12).

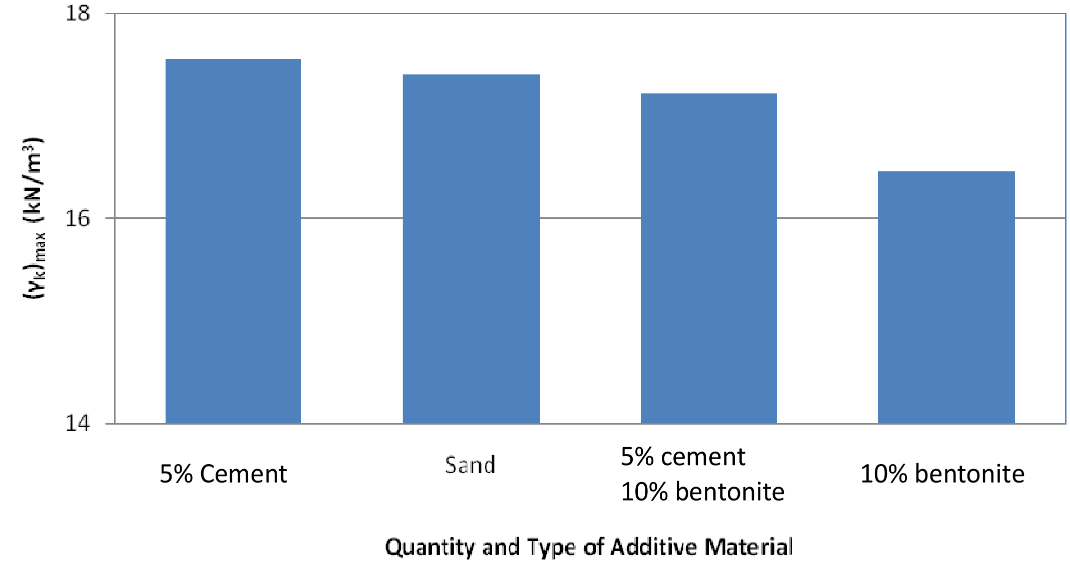

Figure 8. Variation of optimum water content with the admixture type and amount.

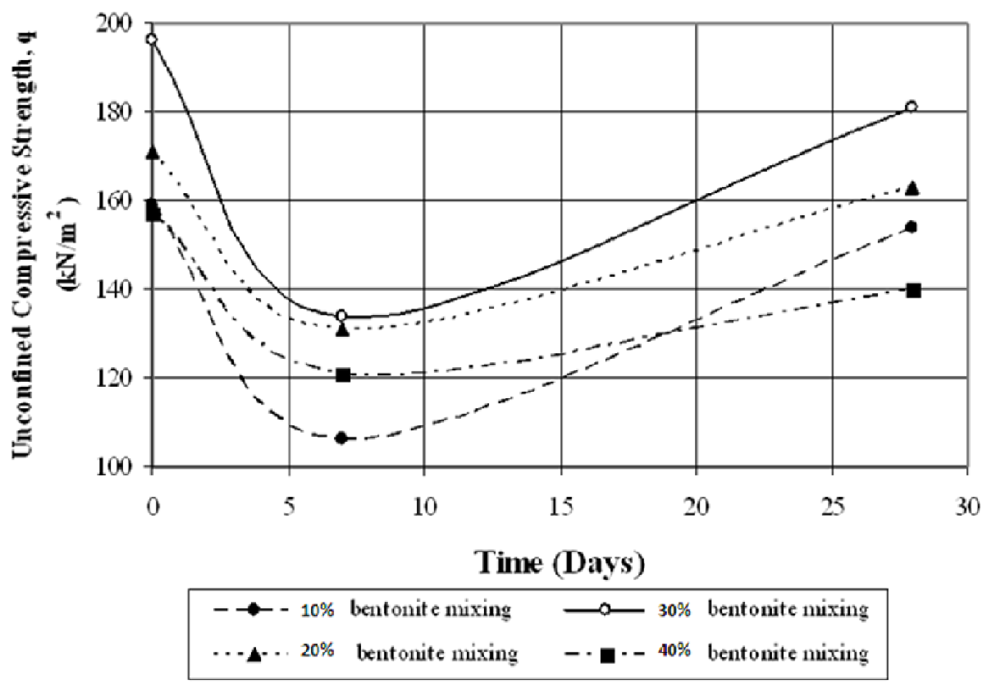

Figure 9. Unconfined compression strength of mixtures with bentonite admixture vs time.

When the unconfined compression strengths of 10% bentonite and 5% cement added mixtures are compared to the strengths of other mixtures, it was seen that the efficient admixture is cement (Figure 13).

Permeability test

The values obtained from falling head permeability tests applied to the prepared soil samples are shown in Table 3.

It can be seen in Figure 14 that permeability (k) decreases with the increase of bentonite ratio in mixtures containing only bentonite admixture. Figure 15 show that k decreases with the increase of cement in the mixtures containing only cement addition.

Figure 16 shows that the k value of the 10% bentonite + 5% cement added mixture is lower than the 10% bentonite added mixture and + 5% bentonite added mixture. The variation of the permeability values of these three mixtures are shown in Figure 16.

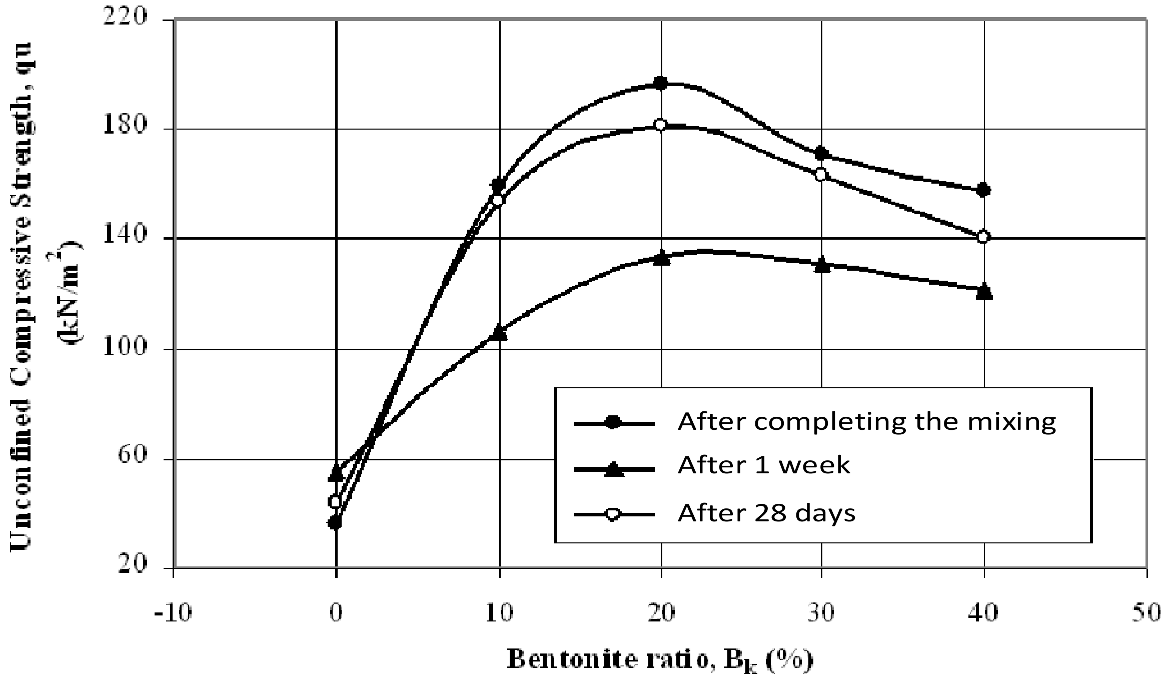

Figure 10. Bentonite percent of samples broken immediately after preperation, one week later and 28 days later vs. unconfined compression strength.

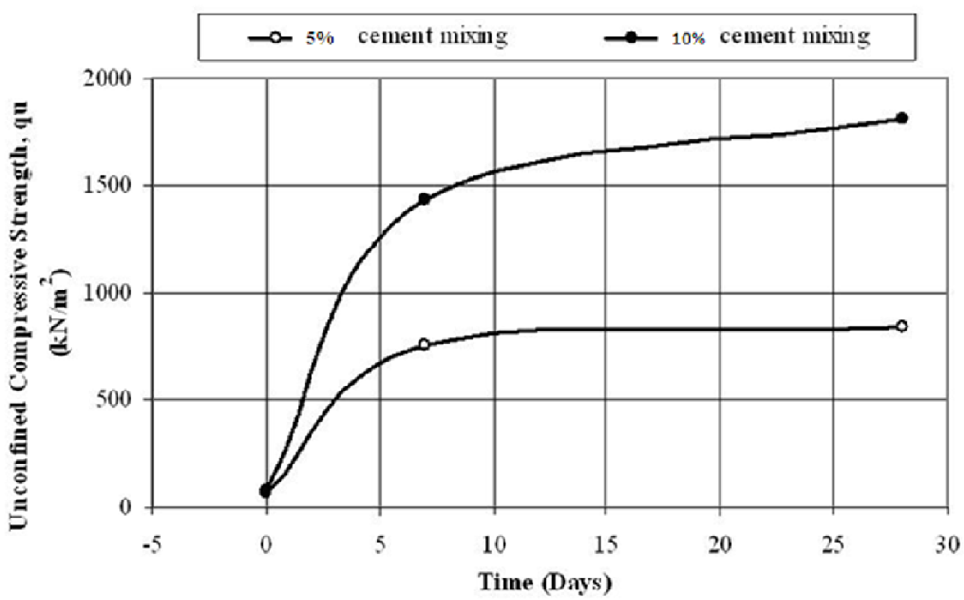

Figure 11. Strength of 5% and 10% Cement Added Mixtures vs Time.

Consolidation test

Consolidation test was applied to 10 and 20% bentonite added samples. During the test, vertical pressure was increased from 0.5 to 16 kN/m2.

Before beginning the experiment, the relative densities of the bentonite added mixtures were found to be 2.476 and 2.312 with the aid of the picnometer test. After the completion of the test, a piece of sample was dried in incubator and water contents after the test were found to be 0.23 and 0.33 respectively. By using the end test water content values, the void ratios are found to be 0.58 and 0.76 at the end of the experiment. By using the sample thicknesses at the start and at the end of the test and the water content at the end of the test, the void ratios at the beginning of the test were

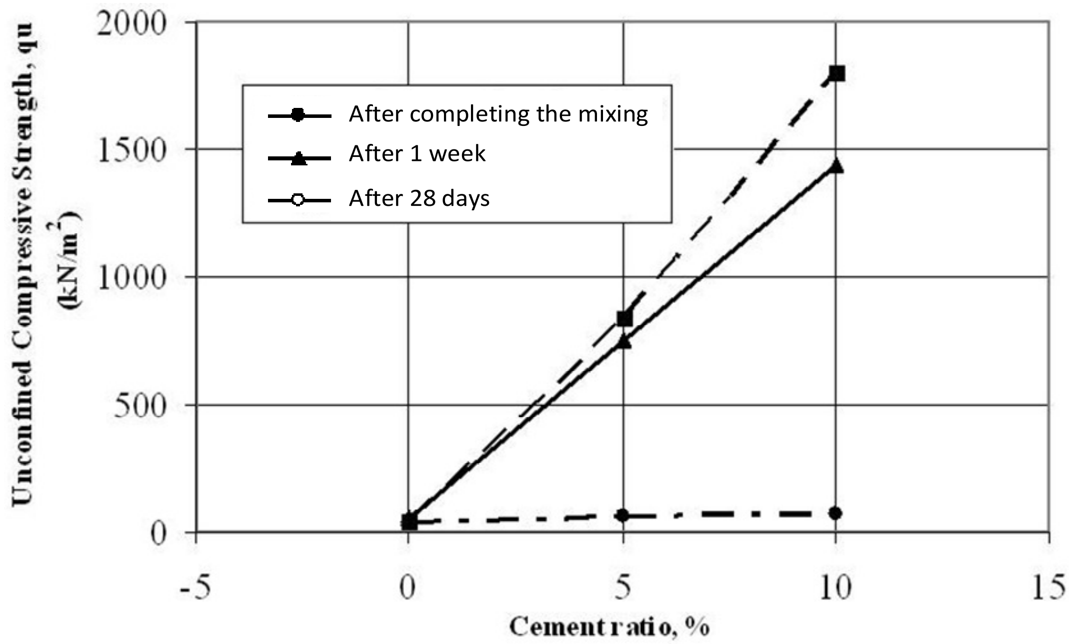

Figure 12. Cement ratio of samples broken immediately, 1 week later and 28 days later vs unconfined compression strength.

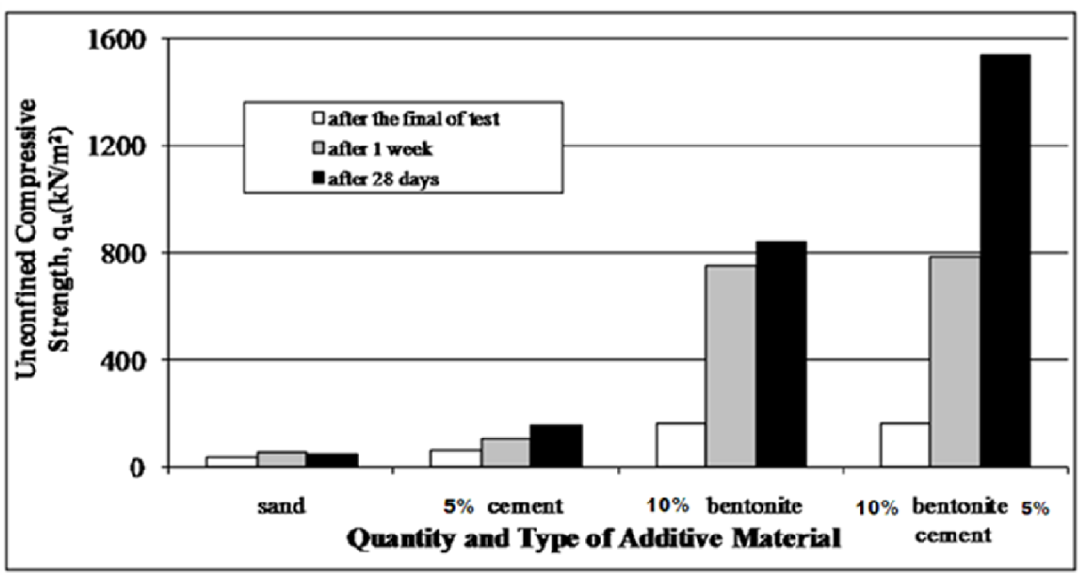

Figure 13. Unconfined Compression Strengths of Samples Broken Immediately, 1 week Later and 28 Days Later

found to be 0.69 and 0.75.

When the ratios of 10% bentonite added sand is investigated, it can be seen that the void ratio at the beginning of the test is lower than the void ratio at the end of the test. The void ratio of the 20% bentonite added mixture at the end of the test is higher than the value at the beginning of the test. Figure 17 shows that no problem is experienced with mixtures having up to 18.5% bentonite ratio and that swelling problems will exist when this ratio is exceeded.

RESULTS

In this study, alternative materials to be used in fillings aimed for impermeability are investigated. Various amounts of bentonite and bentonite-cement mixture is added to sand and their usability is investigated by making compaction, unconfined compression,

Table 3. Permeability values.

Bentonite ratio (%)	Permeability coefficient (cm/s)
10	9.89×10^{-9}
20	4.75×10^{-9}
30	3.21×10^{-9}
40	2.57×10^{-9}
100	9.51×10^{-10}
Cement ratio (%)	
5	4.53×10^{-8}
10	3.5×10^{-8}
Bentonite + cement ratio (%)	
10+5	1.21×10^{-9}
Sand ratio (%)	
100	1.02×10^{-7}

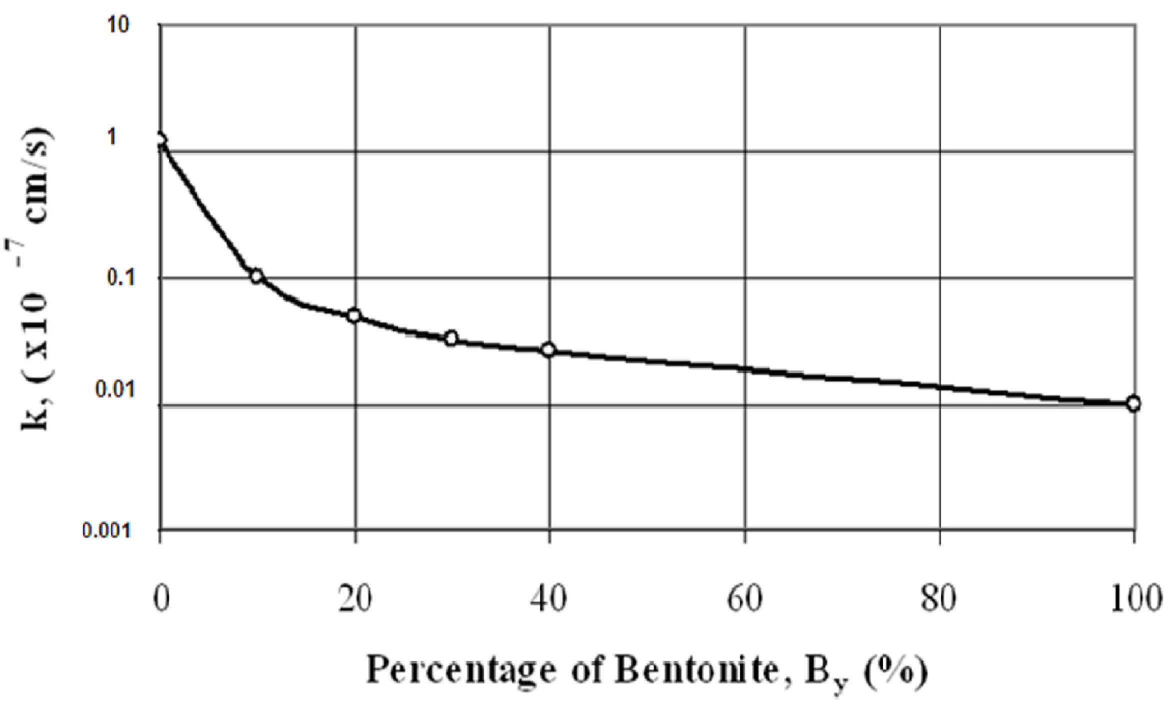

Figure 14. Variation of Permeability with Bentonite Ratio.

permeability and consolidation tests. In all samples prepared by adding bentonite and bentonite-cement mixture, permeability decreased significantly compared to sand. It has been shown with permeability tests that sand with bentonite admixture can be used in the fillings which require impermeability like solid waste storage sites and earth fill dams.

When bentonite is mixed with sand the dry density increases significantly. All factors evaluated in this study mixing ratio of bentonite to sand and cement have significant influences on maximum dry density and optimum moisture content. As the mixing ratio of bentonite to sand changes from % 10 to 40%, the maximum dry density of the bentonite – sand mixtures increases and the corresponding optimum moisture content decreases.

Most of the environmental regulatory agencies require that the hydrolic conductivity of isolation material like compacted bentonite-sand mixture to be less than 1×10-9 m/s. According to the results of falling head hydraulic conductivity tests, this minimum requirement has been satisfied.

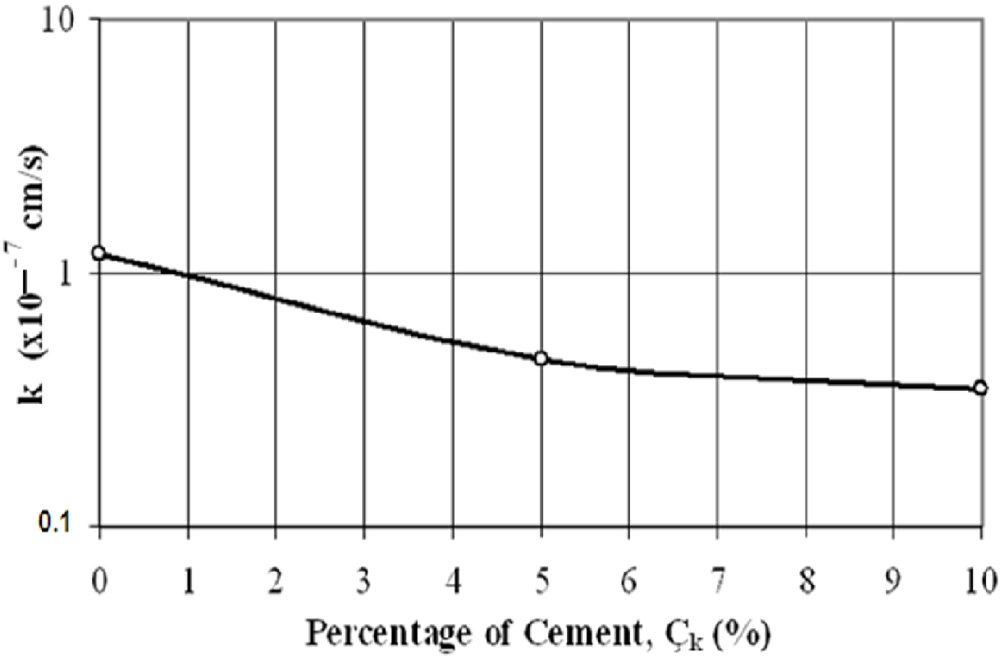

Figure 15. Variation of Permeability with Cement Ratio.

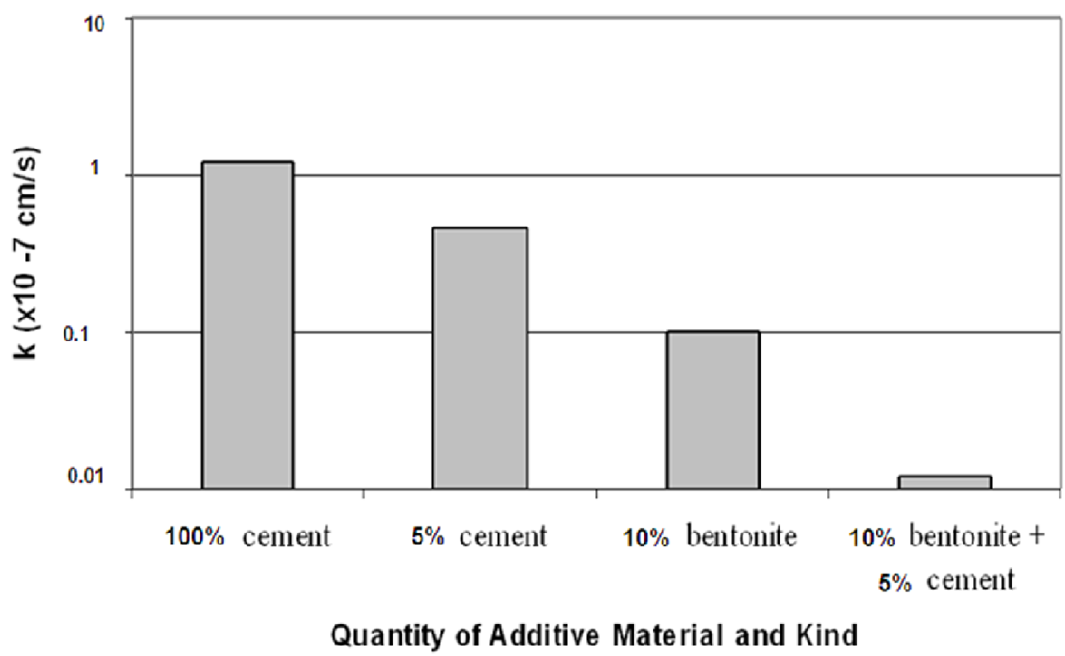

Figure 16. Variation of Permeability According to Admixture Ratios.

As a conclusion a 10% bentonite / sand mixture is recommended for an isolation material to be utilized in underground waste disposal repositories. An optimum 10% bentonite /sand mixture satisfies the minimum requirement of hydrolic conductivity.

Besides impermeability, unconfined compression tests have shown that strength also increased significantly when cement is added with bentonite whenever required.

As a conclusion, a 10 to 20% bentonite/sand mixture is recommended for an unpermeable layer to be utilized

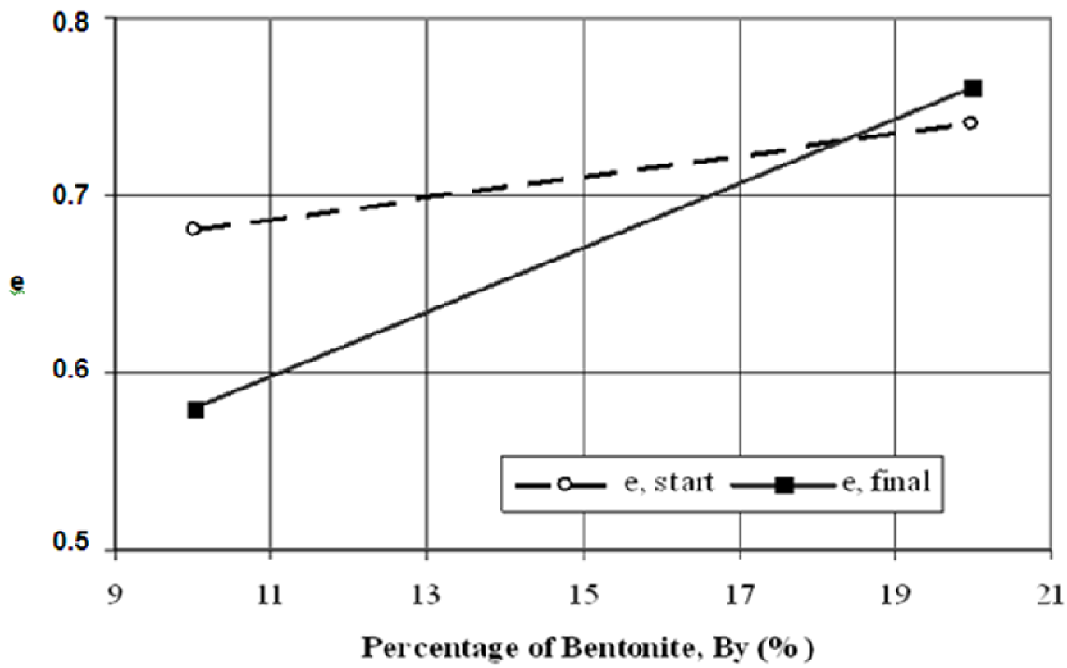

Figure 17. Graph of Bentonite Percent – Void Ratio Variation.

waste disposal repositories.

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