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Evaluation on Mechanical Stabilities of Clay-Sand Mixtures Used as Engineered Barrier for Radioactive Waste Disposal

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Abstract**—**In this study, natural bentonite was used as natural clay material and samples were taken from the Kalecik district in Ankara. In this research, bentonite is the subject of an analysis from standpoint of assessing the basic properties of engineered barriers with respect to the buffer material. Bentonite and sand mixtures were prepared for tests. Some of clay minerals give relatively higher hydraulic conductivity and lower swelling pressure. Generally, hydraulic conductivity of these type clays is lower than $<10^{-12}$ m/s. The hydraulic properties of clay-sand mixtures are evaluated to design engineered barrier specifications. Hydraulic conductivities of bentonite-sand mixture were found in the range of $1.2x10^{-10}$ to $9.3x10^{-10}$ m/s. Optimum B/S mixture ratio was determined as 35% in terms of hydraulic conductivity and mechanical stability. At the second stage of this study, all samples were compacted into cylindrical shape molds (diameter: 50 mm and length: 120 mm). The strength properties of compacted mixtures were better than the compacted bentonite. In addition, the larger content of the quartz sand in the mixture has the greater thermal conductivity.

Keywords**—**Bentonite, hydraulic conductivity, clay, nuclear waste disposal.

I. Introduction

DISPOSAL is the most preferred option for nuclear waste in most countries. Various engineered barrier materials are used in individual national programs for the radioactive-waste management [1]. Diffusion is the basic transport mechanism in deep geological disposal conditions. Basic criterion for selection of natural materials is the hydraulic permeability in a saturated state. For this reason, several clay types are considered for using as buffer material for isolating radioactive waste packages from environment. Swelling pressure is another property of clays by ensuring self-sealing ability for closing gaps in the isolation barriers. Isolation performance of engineered barriers should be evaluated into thermal, hydraulic, mechanical and chemical processes in underground conditions. Effects of temperature in the repository starting from beginning of the design stage due to the decay heat in the waste should be taken into account for these processes. For this reason, hydro-thermo-mechanical and geochemical conditions should be considered in near surface and deep geological repositories. The most important properties of the barrier in a disposal facility are permeability, swelling pressure, thermal conductivity, and retention capacity for radionuclides [2]. Clay-sand mixtures are used as backfill materials because they offer properties of very low permeability and high swelling capacity. The compacted clay soils possess many advantages such as low hydraulic conductivity ($<10^{-9}$ m/s), they have high shrinkage and high expansive potential causing instability problems [3]. Clay-sand mixtures were considered by the design geotechnical and environmental engineers for use as hydraulic barriers. Adding clay to the sand helps in achieving low hydraulic conductivity. The term Bentonite Enhanced Sand (BES) was used by many researchers instead of clay sand mixtures [4]-[6]. Correlation studies of the hydraulic conductivity with clay properties had been investigated by done [7]-[9]. Hydraulic conductivity depends on many bentonite content, exchangeable cations, compaction effort and moisture content. Several factors influencing the hydraulic conductivity of compacted clays was investigated [10], [11]. Compacted clays or mixtures of local soils with clay are investigated because of its low hydraulic conductivity. The hydraulic conductivity can be further reduced by the addition of bentonite to local soils to attain the values specified by international regulations (10^{-7}cm/s) [12]. The hydraulic conductivity of compacted silts decreased with the bentonite content when permeated with distilled water [13].

In natural raw materials, clays are commonly used as absorbent. Clay based raw materials divided into two groups; two layered clay minerals and three layered clay minerals. Kaolinite Group clays have two layers and illite/ montmorillonite Group clays have three layers. The adsorption of radionuclides by clay based raw materials was investigated as a function of different parameters. By using the batch equilibrium technique, distribution ratios of each type of material in batch experiments were determined between Rd =1 and 50 Lkg^{-1} [14]. Properties of Bentonite is one of these absorbent clays. Bentonites provide convenient media for the sorption of ionic particles and trace metals. Sorption mechanism of bentonites is not only on the external surface of the particles, but also in the interlayer spacing of the structural layers with substitution at specific ion-exchange positions as well. Therefore, bentonites have dispersing and absorbing properties. Water saturation of these type of clay based raw materials is between 2000 and 3500 kg/m^3 and in case of contact with radioactive isotopes in aqueous media, radioactive isotopes migrated into the clay interlayer becoming incorporated within the mineral structure [15].

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II. Materials and Methods

Natural bentonite was used as natural clay material for this study, and natural bentonite clay samples were taken from the Kalecik district in Ankara, Turkey. Bentonite beds in this district were generated from andesits and andesitic tuffs. They have white, yellow and green colors due to their ingredients, organic materials and moisture.

Bentonite is commonly used to describe a clay material. Major mineralogical component is characterized as smectite group because it has smectite minerals. The major constituent of bentonite is montmorillonite. In addition, various amount of feldspar, quartz, mica and gypsum generally exist in bentonite. Major elements of bentonite are presented in Table I.

TABLE I
XRF Analysis of Kalecik Bentonite

Basic Elements	Composition %
SiO_2	60-65
Al_2O_3	15-20
Fe_2O_3	4-6
MgO	3-3.5
Na_2O	2-3
K_2O	0.8-1.2
CaO	0.5-1.5

Minor elements in the bentonite was determined in ppm as; Nb, Sr, Zr, La, Th, Y, Zn and Rb.

According to results of characterization analysis of the bentonite; it was determined as Na-bentonite, X-ray diffraction showed a basal spacing of 12.85 Å corresponding to the mineral montmorillonite. Thus, montmorillonite is the major clay mineral and it is dioctahedral smectite type. Specific gravity of Na-bentonite was determined as 2.70 according to ASTM D854-02. Quartz sand was used in this study as sand and its specific gravity was determined almost same with the bentonite as 2.68.

Bentonite samples were kept in laboratory temperature (24 °C). The water contents of samples were measured by remaining them in oven temperature 110 °C for 24 hours. Water content of samples were determined between 8 and 12.0%.

The clay-sand mixtures were prepared by mixing of bentonite and sand. It was prepared by adding of 5%, 10%, 15%, 20%, 25%, %30 and 35% bentonite for laboratory testing to assess their hydraulic conductivity. Specific gravity test results revealed that since the specific gravity of bentonite is almost same with the sand, specific gravity values of bentonite-sand mixtures was taken into account as 2.70. According to increasing bentonite content swelling of the mixture was increasing. However, the addition of more bentonite causes decrease of load bearing capacities of the compacted mixture. According to the hydraulic conductivity test results of B/S mixture, conductivity values were in the range of $1.2x10^{-10}$ to $9.3x10^{-10}$ m/s as seen in Fig. 1.

B/S ratio is directly affect the swelling pressure of the mixture and the unconfined compressive strength. The relationship between the hydraulic conductivity and the swelling property of B/S mixture is inversely proportional. Swelling pressures were found in the range of 20-35 kPa.

Thermal conductivity of compacted samples depends on the dry density and water content. The thermal conductivity increases with the water content and dry density. Thermo-hydro-mechanical studies were carried out in previous researchers for determination of isolation performance in engineered barriers [16].

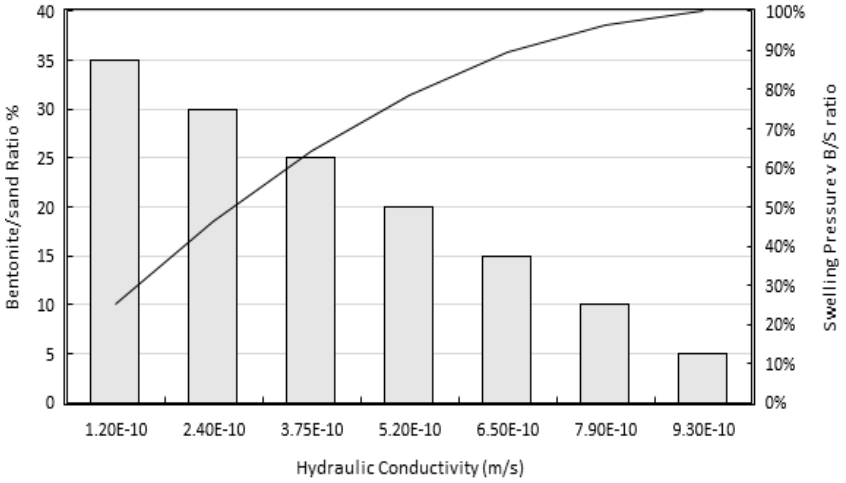


Fig. 1 Hydraulic conductivity of various B/S mixtures

Water content of all samples was arranged by adding of 5%, 10%, 15%, 20%, and 25% water for laboratory testing to assess their thermal conductivity. The larger content of the quartz sand has the greater thermal conductivity as shown in Fig. 2.

According to the experimental results, strength properties of mixture were better than the bentonite. In addition, it is considered to be effective to mix with quartz sand to increase the dry density in order to increase thermal conductivity of buffer material. However, compacted bentonite has sufficient mechanical strength and plasticity to act as a buffer material,

addition of quartz sand increases the strength of the bentonite. The adsorption properties, hydraulic properties of buffer material depend on dry density of compacted bentonite and the montmorillonite content. On the other hand, quartz sand amount in bentonite improves the properties for compact molding and heat conductivity.

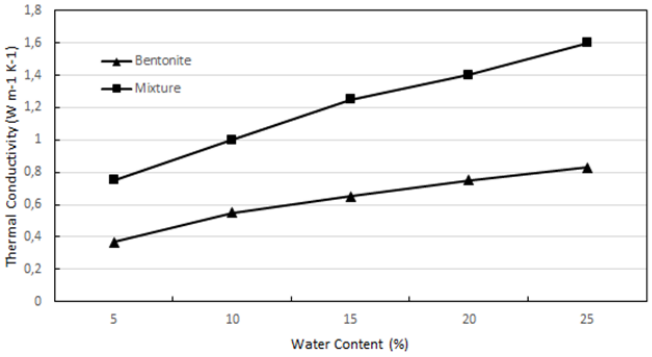


Fig. 2 Thermal conductivity of bentonite and B/S mixture, Assessment of a thermal analysis is an effective parameter for the near field analysis of buffer materials

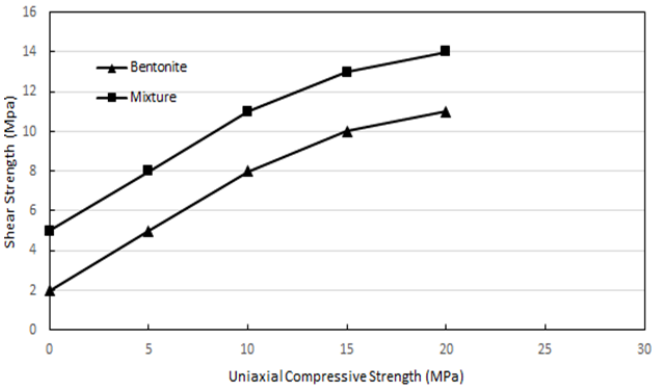


Fig. 3 Uniaxial compressive strength versus shear strength

Bentonite-sand mixture is one of the isolation material as an engineering barrier for waste disposal facilities. Results show that Kalecik bentonite has some unique properties such as a large surface area, ion exchange capacity, high water absorption and expansion. In case of Bentonite-Sand mixture ratio is %35, optimum decrease in hydraulic conductivity with reasonable mechanical stability can be satisfied. Hydraulic conductivity of the Kalecik bentonite and sand mixtures decreases with increasing bentonite content. For high bentonite content 35%, the saturated hydraulic conductivity was determined as 1.20 x 10^{-10} m/s. Distribution of bentonite in mixture depends on the water content during mixing process. Hence, mechanical stability of compacted bentonite depends on several parameters. These are; mixing process, B/S value and water content of the mixture. These parameters should be taken into account for achieving optimum B/S product. Bentonite content to improve the hydraulic performance has negative effects on the mechanical stability of the product. In the near field analysis, the mechanism of radionuclide transport and retardation in barrier materials should be taken into account. Actually, it covers three mechanisms; advection, dispersion and sorption. In this research tests were focused on only sorption mechanism. Because at a very low groundwater flow velocities diffusion is the dominant mechanism of dispersion and it is controlled by molecular diffusion. The migration of radionuclides in the engineered barrier includes mass transport in the buffer caused by diffusion and sorption. Then, from the buffer dissolution/precipitation and radioactive decay. For this reason, the most significant parameters will depend on chemical properties of groundwater. Long-term isolation performance of any engineered barrier should be assessed under geological environment conditions of radioactive waste disposal.

The technical requirements for the landfill of wastes in the European Union (EU) are given in the Council Directive 1999/31/EC. According to this directive, a barrier with a hydraulic conductivity (HC) of 1x10^{-9} m/s is required. Hydraulic conductivity value of Kalecik B/S mixture was determined in accordance with the EC Directive. In case of optimum B/S ratio and adequate mixing process are maintained, compacted Kalecik B/S mixture can be used as isolation barrier material for waste disposal.

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