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Investigation of thermal properties of Zostera marina added zeolite-bentonite mixtures

Zostera marina katkılı zeolit-bentonit karışımlarının termal özelliklerinin araştırılması

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Abstract

The importance and number of energy structures are increasing, and due to the increasing temperature of the soil around these structures, materials that can stabilize or even optimize their resistance to temperature are needed. In this study, Standard Proctor test and thermal conductivity measurement tests of zeolite-bentonite and seaweed added mixtures were carried out by using Zostera marina sea plant, which is frequently used for thermal insulation. It was aimed to examine the seaweed additive from a thermal point of view. Thermal conductivity measurements showed that thermal conductivity increased as the seaweed contribution in the mixture increased. Also, generally the results indicated that seaweed, which has high resistance to thermal changes, is an alternative additive material that can be used in the presence of both seasonal changes and thermal changes caused by energy structures.

Keywords: Seaweed, Temperature, Thermal behavior, Zeolite-Bentonite.

Öz

Enerji yapılarının önemi ve sayısı artış göstermektedir ve bu yapıların çevresindeki zeminlerin sıcaklığının artması nedeniyle, sıcaklığa karşı direncini stabilize edebilecek, hatta optimize edebilecek malzemelere ihtiyaç duyulmaktadır. Bu çalışmada, ısı yalıtımında sıklıkla kullanılan Zostera marina deniz bitkisi kullanılarak zeolit-bentonit ve deniz yosunu katkılı karışımların Standard Proctor deneyi *ve termal iletkenlik ölçüm testleri yapılmıştır. Deniz yosunu katkı maddesinin termal açıdan incelenmesi amaçlanmaktadır. Isıl iletkenlik ölçümleri, karışımdaki yosun katkısı arttıkça ısıl iletkenliğin arttığını göstermiştir. Ayrıca genel olarak sonuçlar, termal değişimlere karşı direnci yüksek olan deniz yosununun hem mevsimsel değişimler hem de enerji yapılarından kaynaklanan termal değişimler varlığında kullanılabilecek alternatif bir katkı malzemesi olduğunu göstermiştir.*

Anahtar kelimeler: Deniz yosunu, Sıcaklık, Termal davranış, Zeolit-Bentonit.

1 Introduction

The number of researches on the need for energy and alternative energy sources is increasing day by day. Considering that fossil fuels are low sustainability, expensive, harmful to the environment, an increase in the number of energy geo-structures is observed. Temperature changes occurring around energy geo-structures and facilities such as nuclear waste storage areas, solid waste storage areas, and heat piles affect the engineering properties of the soils at the design stage.

Alternative materials that can preserve soil engineering properties such as shear strength, compressibility parameters, hydraulic conductivity behavior in the presence of temperature changes are needed. The materials generally used as buffers for high temperatures and temperature changes are bentonite or sand-bentonite mixtures due to their impermeable structure [1]. Nuclear waste storage areas are considered as an energy structure where the soil interacts with the temperature generated by the decay of radioactive waste and the temperature must be removed with the buffer material to be used.

In nuclear waste storage areas, radioactive wastes are stacked regularly in a copper container, usually called a "canister", and placed in a rock very deep underground. This depth varies depending on each country's nuclear waste disposal method and practice. While this depth is approximately 600-800 m in Sweden, it can reach 900 m in Switzerland or vary between 500-1000 m in countries such as Canada [2]-[3].

The canister container in which the radioactive waste is placed is covered with a buffer material to prevent damage from both leachate that may be present in groundwater and the movement of the bedrock [4]. This buffer material must also have a structure that functions against high temperatures and can even optimize the technical properties that need to be protected in the presence of temperature. Because in areas where HLW is stored, temperature values reaching or even exceeding approximately 100 °C occur [3]. Figure 1 is demonstration of the use of bentonite disc in buffer design [5].

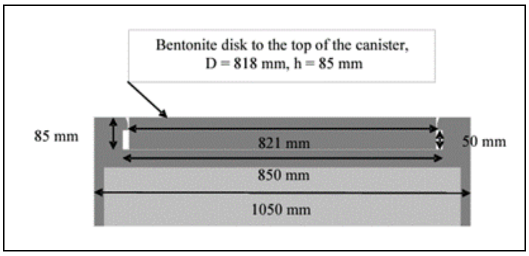

Figure 1. Demonstration of the use of bentonite disc in buffer design [5].

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Buffer materials with high thermal conductivity are needed to reduce and optimize these high temperature values occurring in the temperature source (canister) and to transmit them towards the bedrock. The material chosen as a buffer must have very low permeability and be able to maintain its properties throughout its lifetime [3]. There are currently used materials and mixtures for this purpose: bentonite or sand-bentonite. The Figure 1 shows an illustration of the use of bentonite as a buffer. Bentonite is selected as a buffer material due to its high absorption capacity, self-sealing properties, low hydraulic conductivity and durability properties [6]-[7]. On the other hand, undesirable and unexpected deformations occur as a result of the evaporation of water in bentonite in the presence of high temperatures [8]. For this reason, sand-bentonite mixtures are preferred as buffer material in some storage areas. Considering the strength-increasing effect of sand, the inability of bentonite to fill the voids as the sand content increases, and the decrease in permeability due to the dry density-reducing effect of bentonite alone, sand-bentonite mixtures are frequently used as buffers [9]-[10].

Nowadays, when environmental pollution increases and sustainability becomes more important day by day, it is very important to use environmentally friendly alternative materials. Zostera marina is a marine plant that grows faster under high temperatures and is tolerant to heat [11]. In the east coast of USA, it shows maximum growth between June and July [12]. The role of seaweed in climate change should not be ignored. With the increased use of seaweed, CO_2 emissions will also be balanced [13]. The release of seaweed causes the sinking and retention of CO_2 in the depths of the oceans [14].

Zostera marina is an important part of marine ecosystems due to its functions and mechanisms. Carbon is produced in their structure and removed at the same time. They have a significant impact on increasing biodiversity [15]. Zostera marina has been used for years for purposes requiring resistance to temperature changes, such as roof insulation, in countries with cold climate conditions such as Denmark [16]. Figure 2 shows the locations of Zostera marina samples collected from different regions in Denmark to be used in experiments.

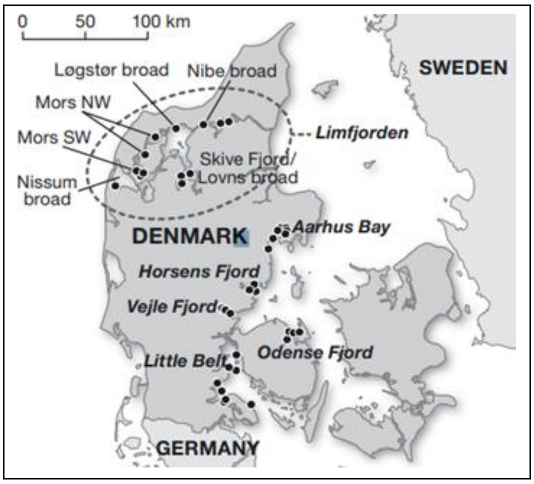

Figure 2. Map from a study taking sample samples from Zostera marina in Denmark [15].

The fact that high temperatures accelerate the photosynthesis of seaweeds and increase the amount of oxygen forms the basis of this plant's resistance to temperature changes [18]. Figure 3 shows an image of seaweed in the ocean.

Figure 3. Seaweeds found in the ocean [19].

In this study, it was aimed to use an alternative buffer material to be used around the canister in nuclear waste storage areas by adding dried seaweed (Zostera marina) additive to zeolite-bentonite mixtures. In this regard, it was investigated whether zeolite-bentonite and dried seaweed-added mixtures had the required thermal properties to be used as buffer materials as intended. The dried seaweed added zeolite-bentonite mixtures were used and compaction tests and thermal conductivity measurements were performed on the mixtures in order to create buffer material around nuclear waste storage areas.

2 Material characterization and methods

2.1 Material characterization

Zeolite, bentonite and dried seaweed were provided from local suppliers (Figure 4). The bentonite used is sodium bentonite. Seaweed used in dried form was added to zeolite-bentonite mixtures. When naming the mixtures, "Z" was chosen as zeolite, "B" as bentonite and "SW" as seaweed.

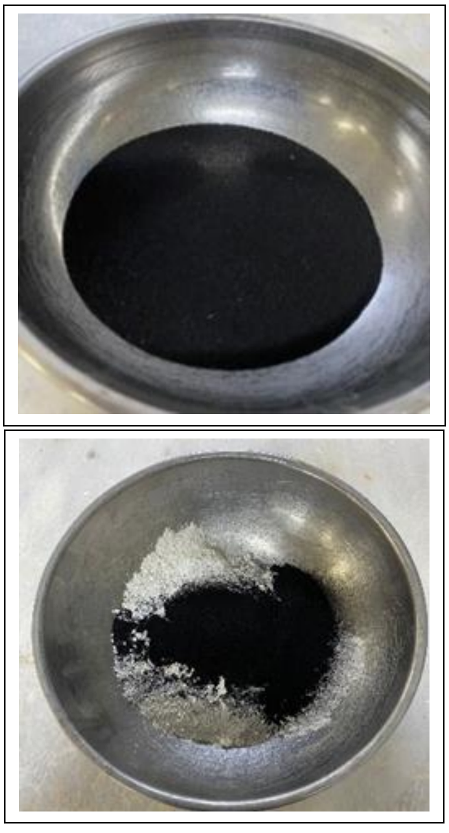

Figure 4. Dried seaweed sample and dry mixture used in tests.

XRD analysis results of the zeolite and bentonite mixtures used in the experiments are given in Figure 5.

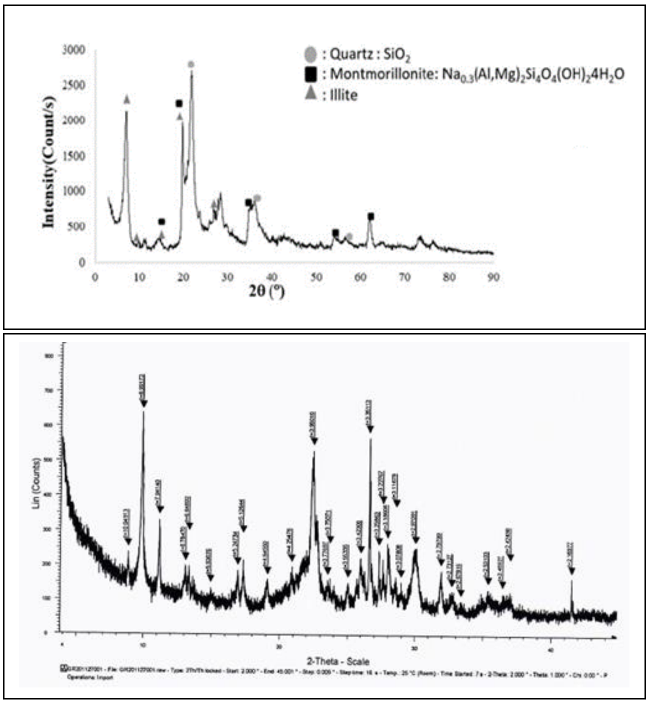

Figure 5. XRD analysis results of bentonite and zeolite.

The results showed that klinoptilolite, quartz, feldspar and illite-mica were present in the zeolite, and montmorillonite, quartz and illite minerals were present in the bentonite sample. Klinoptilolite mineral is the main mineral of zeolite and constitutes 80% of the zeolite. The properties of the materials are given in Table 1.

Table 1. Physico-chemical properties of the materials used in the tests.

Property	Zeolite	Bentonite
Specific gravity	2.40	2.70
Liquid limit (%)	50.0	476.0
Plastic limit (%)	N.P.	70.1
pH	7.6	9.5

In the experiments, the materials were used in their natural state, without being dried. The clay fraction of bentonite was 60%. Seaweed was dried and used in powder form. The material contents in the mixtures were 60% zeolite, 40% bentonite and 10% and 20% dried seaweed additive based on the total dry weight. Table 2 shows the characteristics of seaweed.

Table 1 Properties of the dried seaweed used in the tests.

Property	Dried seaweed
Habitat	Aquatic
Leaf Position	Under Water
Underwater Leaf Length	Max. 1100 mm
Underwater Leaf Blade Width	2-12 mm

2.2 Experimental methods

In this study, compaction curves, thermal conductivity and other necessary thermal parameters of additive free and dried seaweed-added zeolite-bentonite mixtures were determined. In the experiments to be performed in the laboratory environment within the scope of the study, the suitability of laboratory conditions is very important. Studies have suggested opening windows and increasing ventilation in order to prevent the increase in CO_2 concentration in the laboratory environment [20].

2.2.1 Standard proctor test

In this study, the 40% bentonite-60% zeolite contents were kept constant and mixtures were created using 10% and 20% dried seaweed additives. For the compaction test, the samples were weighed in dry form. Samples were prepared in different water contents. After mixing, it was kept in a closed container for 24 hours. Standard Proctor tests were performed (Figure 6) according to ASTM D698-12 [21].

Figure 6. Standard proctor test equipment.

2.2.2 Thermal conductivity measurement

Before performing thermal conductivity measurements, the mixtures were first mixed in dry form. Then, it was prepared according to the w_{opt} and $\gamma_{max, dry}$ parameters obtained from the compaction tests and kept closed for 24 hours. After the homogeneous distribution of water in the mixture was completed, the samples were compacted into the measurement mold.

Thermal properties analyzer (TEMPOS) was used to determine thermal conductivity (W/mK) and other thermal parameters (Figure 7).

Figure 7. TEMPOS thermal properties analyzer.

Thermal conductivity and volumetric heat capacity values were determined using different probes. Heat capacity and specific heat values were observed with the help of these parameters. Heat capacity and specific heat formulas are given below:

$$\text{Heat capacity } (J/m^3K) = \text{Volumetric heat capacity} \times 10^6 \quad (1)$$

$$\text{Specific heat } (J/kgK) = \text{Heat capacity} / \gamma_n \quad (2)$$

3 Results

The compaction tests of the additive free zeolite-bentonite mixture and dried seaweed-added mixtures were carried out. Experimental results showed that as the seaweed content increased, the optimum water content increased (Figure 8) and the maximum dry unit weight value decreased (Table 3).

Table 3. Standard Proctor test data for the mixtures.

Mixture	w_{opt} (%)	$\gamma_{dry,\,max}$ (kN/m^3)
60Z-40B	53.0	9.9
60Z-40B-10SW	55.0	9.6
60Z-40B-20SW	60.0	9.4

It is known that seaweed is a lighter material and has higher water retention properties than bentonite and zeolite. Previous compaction tests have shown that w_{opt} also depends on the clay content [22].

The measurement results of the thermal conductivity values and other thermal parameters are given in Table 4. As a result of the measurements, the thermal conductivity value of the zeolite-bentonite mixture was determined as 0.682 W/mK, and as 10% and 20% dried seaweed were added to the mixture, thermal conductivity value increased to 0.797 and 0.845 W/mK values, respectively.

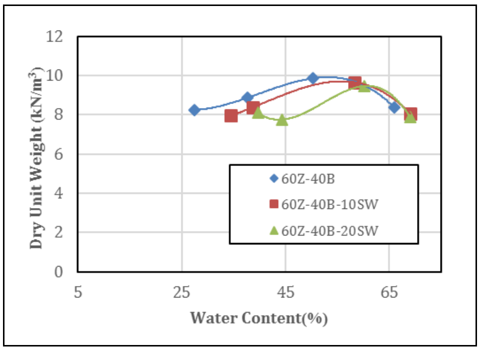

Figure 8. Compaction curves of the mixtures.

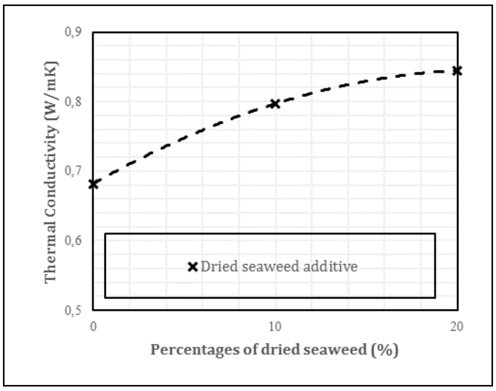

Figure 9. Effect of seaweed additive on thermal conductivity.

Within the scope of this study, the thermal parameters, especially the thermal conductivity, of the zeolite-bentonite mixture and seaweed-added zeolite-bentonite mixtures were measured and determined. All data obtained for the mixtures are given in Table 4. While the thermal conductivity value of the additive-free mixture was 0.682 W/mK, this value increased to 0.797 W/mK and 0.745 W/mK with 10% and 20% SW additive, respectively. These results show that the dried seaweed additive makes the mixture more thermally conductive (Figure 9). Heat capacity is the amount of heat required to change the temperature of a substance by 1 °C, and it has been shown that heat capacity also increases with additive.

In literature studies, boron-added (colemanite, ulexite and tincal) sand-bentonite mixtures were tested for use in the presence of high temperatures and temperature cycles around energy geo-structures [23], as well as glass fiber, perlite, pumice [24] additive materials were also used in sand-kaolin mixtures. While some of the alternative additive materials used in these studies were sufficient in terms of hydraulic conductivity behavior, some were found sufficient in terms of different engineering parameters such as compressibility, swelling and shear strength behaviors. In this study, dried seaweed was examined in terms of thermal conductivity and other thermal parameters, and it was found worth examining the other engineering parameters mentioned in future studies.

4 Conclusion

In the present study, the compaction experiments of zeolite-bentonite and dried seaweed-added zeolite-bentonite mixtures were performed and thermal conductivity measurements were carried out. In addition to thermal conductivity values, other thermal parameters such as specific heat and heat capacity were also determined. When the results compared, it was seen that the thermal conductivity increased as the amount of seaweed additive in the mixture increased. This increase reveals that seaweed-added mixtures have the potential to remove high temperatures from the heat source in areas such as nuclear waste storage areas, where they are intended to be used as an alternative buffer material.

This study is of great importance for future studies as an alternative additive material produces remarkable results in a globalizing world where sustainability becomes more important day by day.

5 Author contribution statements

In this study, the author contributed to the creation of the idea, design and literature review, and evaluation of the results obtained. He also took part in providing the materials used, examining compliance with spelling rules, and checking the article for content. It enabled the results to be examined.

6 Ethics committee approval and conflict of interest statement

"There is no need to obtain permission from the ethics committee for the article prepared".

"There is no conflict of interest with any person / institution in the article prepared".

Table 4. Thermal properties of the mixtures

Mixture	Thermal conductivity (W/mK)	Volumetric heat capacity (MJ/m^{3}K)	Heat capacity (J/m^{3}K)	γ_v (kg/m^3)	Specific heat (J/kgK)
40B-60Z	0.682	3.337	3337000	1009.5	3305
40B-60Z-10SW	0.797	3.429	3429000	978.9	3502
40B-60Z-20SW	0.845	3.445	3445000	958.5	3594

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