

# Shear strength behaviour of sand-bentonite mixtures with pumice additive under high temperature

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**Abstract.** Depending on increase in the number and type of energy geostructures, studies on the change in soil behavior against heat increase becomes more important. The engineering properties such as permeability, volume deformation of surrounding soils around energy structures mustn't alter in the presence of heat and thermal cycles. Pumice is a material used in many fields especially for thermal insulation. For that reason, pumice can be used for increasing the resistance of soils in the presence of heat. In this study, the shear strength behavior of sand-bentonite mixtures was investigated with pumice additive under high temperature. In the experiments, 10% and 20% pumice were added to 10% and 20% sand-bentonite mixtures and compaction, direct shear tests were conducted. The direct shear tests were performed both room temperature and under 80°C. The results have shown that the pumice additive increased the shear strength of sand-bentonite mixtures under high temperature when compared the test results under room temperature.

## 1 Introduction

The increase in the number of energy geostructures increased the importance of interaction between the soil and energy structure and soil behavior under high temperatures. Today use of many structures or elements such as energy piles, buried power cables, solid waste and nuclear waste storage areas, etc., which cause soils to be exposed to high temperatures. The behavior of soils in the presence of temperature varies in many respects. For example, the shear strength of the normally consolidated clay increases with increasing soil temperature. Also the studies have shown that the slope of the shear strength envelope is independent of the temperature [1]. In previous literature studies, it was found that the effect of temperature on shear strength is significantly dependent on volume changes caused by heating called thermal consolidation [2]. In another study, the triaxial compression tests on Pontida silty clay showed that in the temperature range of 18°C to 115°C, the shear strength and hardness of this silty clay decreased with increasing temperature [3].

Pumice is a type of volcanic rock used in many different sectors such as filtration, ceramic, construction, textile, agriculture, chemistry, especially heat and sound insulation. Pumice is a highly porous material and usually there is no connection between these pores. Lack of connection between the pores will not allow water to flow. Therefore, pumice was characterized as a low permeability material. In addition, it has very low thermal conductivity. Pumice is available in two forms in nature, as acidic and basic. Acidic pumice has white and

dirty white color and basic pumice has brown or black color. The density of acidic pumice is lower than the basic pumice.

Pumice is an amorphous aluminum silicate formed as a result of volcanic activities. Chemical structure of pumice includes 60-70% SiO<sub>2</sub>, 13-15% Al<sub>2</sub>O<sub>3</sub>, 1-4% Fe<sub>2</sub>O<sub>3</sub>, 1-2% CaO, 1-2% MgO, 2-5% Na<sub>2</sub>O, 3-4% K<sub>2</sub>O and it also contains TiO<sub>2</sub>, SO<sub>3</sub> [4, 5]. Aluminum oxide in the chemical structure of pumice is known to provide high heat resistance [6]. The ton price of the pumice used in the experiments is about \$4.4 (US Dollars). This additional information shows that the use of pumice in such applications is also very cost-effective.

Especially in solid waste and nuclear waste storage areas, only bentonite or bentonite-sand mixtures are used as a buffer because of its low permeability and high swelling properties [7]. Generally, bentonite is mixed with sand and used as a reinforced filling material with high thermal conductivity and stiffness [8-10]. The use of bentonite by mixing with sand instead of using it alone is because sand content will compensate occurrence of shrinkage cracks.

In this study, shear strength behavior of sand-bentonite mixtures was investigated under room and high temperature in the presence of 10% and 20% pumice. The effect of pumice addition on the shear strength behavior of sand-bentonite mixtures were examined.

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## 2 Material and Method

### 2.1 Material Characterization

In this study, the tests were carried out on the sand-bentonite mixtures. Sodium bentonite was supplied from Eczacıbaşı Esan Mining Company. Pumice was provided from Pomza Export Mining Company. 20.7% of the sand used is fine grained and it was used as sieved through No.6 sieve. Also the bentonite and pumice was sieved through No.40 sieve. The sand and bentonite samples were dried for 24 hours in the oven at 105°C. Pumice has a natural water content of 2% to 5% and it was used without drying. The 10% bentonite-sand and 20% bentonite-sand mixtures were used in the tests and these mixtures will be called as 10B-90S and 20B-80S, respectively. The dry unit weight of the pumice is 12.9 kN/m<sup>3</sup>. The physico-chemical properties of the used materials are given in Table 1.

**Table 1.** The physico-chemical properties of the materials

Property	Sample		
	Bentonite	Sand	Pumice
Specific gravity	2.70	2.63	2.50
Liquid limit	476.0	-	37.1
Plastic limit	70.10	-	NP
pH	9.50	-	8.86

### 2.2 Method

Direct shear tests were performed according to American Society of Testing Materials Standards ASTM D3080 (2011). The samples were prepared by compressing in three layers in a metal mold at maximum dry unit weight and remaining on the 2% wet side of the optimum water content. After compaction of the samples, they were left submerged condition for 24 hours and weights were placed on them in order to prevent swelling. The samples were placed into mold having dimensions of 6x6 cm in the test instrument and left for consolidation, then the test was carried out. Direct shear experiments were performed both at room temperature and under 80°C.

The high temperature in the experiments is provided by the heat rod specially designed for shear box. The K type thermocouples were used to control temperature inside both soil and water. The temperature of the water and soil were measured and recorded by using digital thermometers.

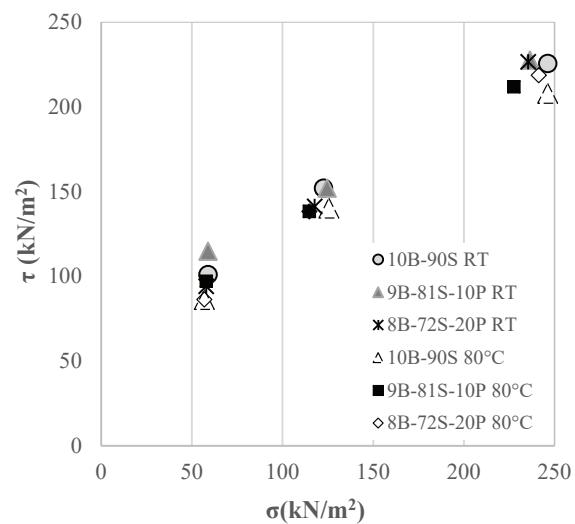
## 3 Test Results

The samples were prepared according to the maximum dry unit weight and 2% wet side of the optimum water content values obtained from Standard Proctor tests. The maximum dry unit weight and optimum water content values are given in Table 2.

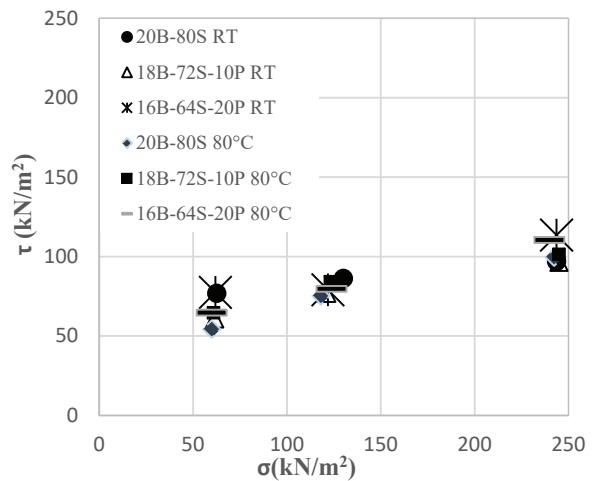
**Table 2.** The compaction parameters of the mixtures obtained from standard Proctor tests

	Sample	$\gamma_{dmax}$ (kN/m <sup>3</sup> )	$W_{opt}$ (%)
		Pumice (P)	12.98
10% Bentonite	10B-90S	16.70	15.5
	9B-81S-10P	16.30	17.0
	8B-72S-20P	15.70	16.0
20% Bentonite	20B-80S	15.60	17.5
	18B-72S-10P	15.20	17.0
	16B-64S-20P	14.80	17.0

The maximum shear stress values of 10% and 20% bentonite-sand mixtures in the presence of 10% and 20% pumice were given in the Figure 1 and 2. Direct shear tests were carried out under two different temperature conditions, under room temperature and high temperature (80°C) and the results were compared.



**Fig. 1.**  $\tau$ - $\sigma$  graphics of 10% bentonite-sand mixtures in the presence of pumice



**Fig. 2.**  $\tau$ - $\sigma$  graphics of 20% bentonite-sand mixtures in the presence of pumice

The internal friction angle of the additive free mixture with 10% bentonite was  $33.1^\circ$  at room temperature. This value decreased with 10% pumice additive but reached  $36.7^\circ$  with 20% pumice additive. At  $80^\circ\text{C}$ , the internal friction angle increased from  $32.2^\circ$  to  $33.8^\circ$  with 10% pumice and  $35.1^\circ$  with 20% pumice by showing a significant trend as pumice was added to the 10B-90S mixtures. These findings indicate that pumice additive has an effect on increasing the internal friction angle of 10% bentonite-sand mixtures under high temperature. However, this increase was not seen in maximum shear stress values. Pumice additive decreased the maximum shear strength value from 140.2 kPa to 138.3 kPa under 98 kPa normal stress at  $80^\circ\text{C}$  however at other stress levels this value increased. Under the 98 kPa normal stress, shear stress values reduced to 141.2 kPa with 20% pumice additive, while it was 152 kPa for additive free mixture. The cohesion value decreased for all 10% bentonite mixtures when shifting from room temperature to  $80^\circ\text{C}$  (Table 3).

**Table 3.** The internal friction angle and cohesion values of Sand-Bentonite mixtures with pumice additive at room temperature and high temperature

Mixtures	Room Temperature		$80^\circ\text{C}$	
	$\phi$ ( $^\circ$ )	c (kPa)	$\phi$ ( $^\circ$ )	c (kPa)
10B- 90S	33.1	66.5	32.2	54.5
9B-81S-10PU	32.4	75.8	33.8	59.6
8B-72S-20PU	36.7	51.9	35.1	50.7
20B- 80S	6.2	70.8	13.5	42.8
18B-72S-10PU	10.7	51.1	10.9	56.0
16B-64S-20PU	11.9	60.0	14.3	48.9

Pumice addition to the 20% bentonite-sand mixtures increased the internal friction angles under room temperature. However, at  $80^\circ\text{C}$ , this increment was only approximately  $0.8^\circ$  which increased from  $13.5^\circ$  to  $14.3^\circ$  for 20% pumice addition. The cohesion values were determined as 70.8 kPa, 51.1 kPa and 60.0 kPa in the 20B-80S mixture, with 10% and 20% pumice mixtures, respectively, under room temperature. The shear stress value of the 20B-80S mixture at  $80^\circ\text{C}$  and under 98 kPa normal stress was 75.3 kPa while this value increased to 84.2 kPa and 79.6 kPa with 10% and 20% pumice addition, respectively. The shear stress value of the 20B-80S mixture at  $80^\circ\text{C}$  (under 98 kPa) was 75.3 kPa while this value increased to 84.2 kPa with 10% pumice additive and 79.6 kPa with 20% pumice additive. Generally, under high temperature, the shear strength increased with pumice additive for the 20B-80S mixture.

## 4 Conclusions

In this study, direct shear tests were conducted on the pumice added 10% and 20% bentonite-sand mixtures under room temperature and high temperature. It has been observed that the internal friction angle increases as the pumice amount increases for 10% and 20% bentonite-sand mixtures at room temperature and  $80^\circ\text{C}$ . The maximum shear stress value increased under high temperature at 98 kPa normal stress level for 20B-90S mixtures. As a result of the direct shear tests, it has been observed that the pumice additive did not increase the shear strength under room temperature. On the other hand, it was determined that in the 20% bentonite-sand mixtures pumice additive increases the shear strength under high temperature. The experimental results showed that pumice additive can be used as an additive to increase shear strength of sand-bentonite mixtures where high temperature is present.

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