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Investigation of the effect of Isparta pumice on the unconfined compressive strength and swelling pressure of clay

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Abstract

This study investigates the effect of pumice, known as Karakaya pumice, and taken from the Isparta-Gölcük region, on clay's unconfined compressive strength and swelling pressure. For this purpose, the physical and index properties of the clay and pumice were determined and then 10%, 15%, 20%, 30%, 40%, and 50% pumice by weight were mixed with clay. Standard compaction tests were performed on clay, pumice, and clay-pumice mixture. With these experiments, the effect of pumice on compaction parameters was evaluated. Samples were prepared under optimum water content and maximum dry unit weight conditions to conduct unconfined compressive strength and swelling tests. The results show that as the pumice additive ratio increased up to 30%, the unconfined compressive strength also increased. However, it was observed that when the additive ratio exceeded 30%, the unconfined compressive strength decreased. The results of the swelling pressure test indicate that as the amount of pumice in the mixture increases, the swelling pressure decreases. It has been determined that Isparta pumice can effectively stabilize compacted clay, reducing its swelling pressure and increasing its unconfined compressive strength. The recommended rate for adding pumice to the clay is 30%.

1. Introduction

Pumice is created during a volcano eruption when frothy scum on a lava flow traps bubbles in it. It's a very lightweight rock that is porous, spongy, and resistant to physical and chemical effects. Pumice also has high sound and heat insulation properties. Because of these characteristics, pumice is widely used in various industries and technological applications such as construction, architecture, environment, textile, agriculture, and chemistry.

Compacted soil fills serve various engineering purposes, such as constructing roads, airport runways, raising construction area levels, dams, and water channels. However, the soils used in filling don't always have the desired properties. In such cases, soils are mixed with additional materials to achieve compaction. These extra materials can include tree peel, rice husk ash, fibers, wood shavings, chips, sea peel, pumice, froth concrete, thermic power station ash, fly ash, volcanic ash, lime, cement, auto tire pieces, industrial churn, marble powder, and gravel [1-5].

Demiröz and Diker [6] demonstrated the geotechnical properties of lightweight fill materials such as EPS (Expanded Polystyrene Foam), waste tire, sand, and cement. They conducted unconfined compression tests, California bearing ratio (CBR) tests, and freeze-thaw cycle tests on the produced specimens to determine the optimal mixing ratio for lightweight fillers. They mentioned that the quantity of EPS and cement used in unconfined compressive testing impacts the experimental results. The findings revealed that the strength decreased as the EPS amount increased, but increased as the cement amount increased. Kamon and Nontananandh [7] showed that the material obtained by mixing industrial wastes (waste from rubber, sugar, beer, and steel factories) with lime can be applied in stabilizing loose and organic soils. Ng and Pang [8] and Ng and Chiu [9] conducted 3 series of triaxial stress path tests to investigate the stress-strain relationship and volumetric behavior of a loosely compacted unsaturated decomposed volcanic soil. They discovered that when saturated loose volcanic soil undergoes isotropic compression, it behaves like clay, but under undrained shear, it exhibits behavior similar to sand. Beyene et al. [10] conducted an experimental study to examine the stabilizing potential of waste ceramic dust and natural lime in altering the geotechnical properties of highly plastic subgrade material. Their research indicated that the optimal dosage for natural lime was 6%, while for waste ceramic, it was 20% for creating safe road subgrades. Hossain [11-12] stated that adding 15-25% pumice to soil or concrete increases strength, but higher ratios lead to strength problems.

In this study, we are examining the impact of pumice on the unconfined compressive strength and swelling pressure of high-plasticity clay. Pumice, a natural material utilized in various research fields, is being considered for usage in stabilizing high-plasticity clay. To investigate this, we are blending pumice with high-plasticity clay at some ratios and analyzing its effects on the engineering properties of the clay.

2. Material and method

2.1. Definition of samples

Sieve and hydrometer analyses, consistency limits, pycnometer, and standard compaction tests were conducted according to ASTM standards [13-17]. The dry unit weight and water content relations are depicted in Figure 1, while the test results are presented in Table 1. In Figure 1, the maximum dry density and optimum water content of clay are 1.19 g/cm^3 and 38%, respectively. For pumice, those amounts are 1.07 g/cm^3 and 16%, respectively. Pumice has a lower optimum water content and maximum dry unit volume weight comparing clay.

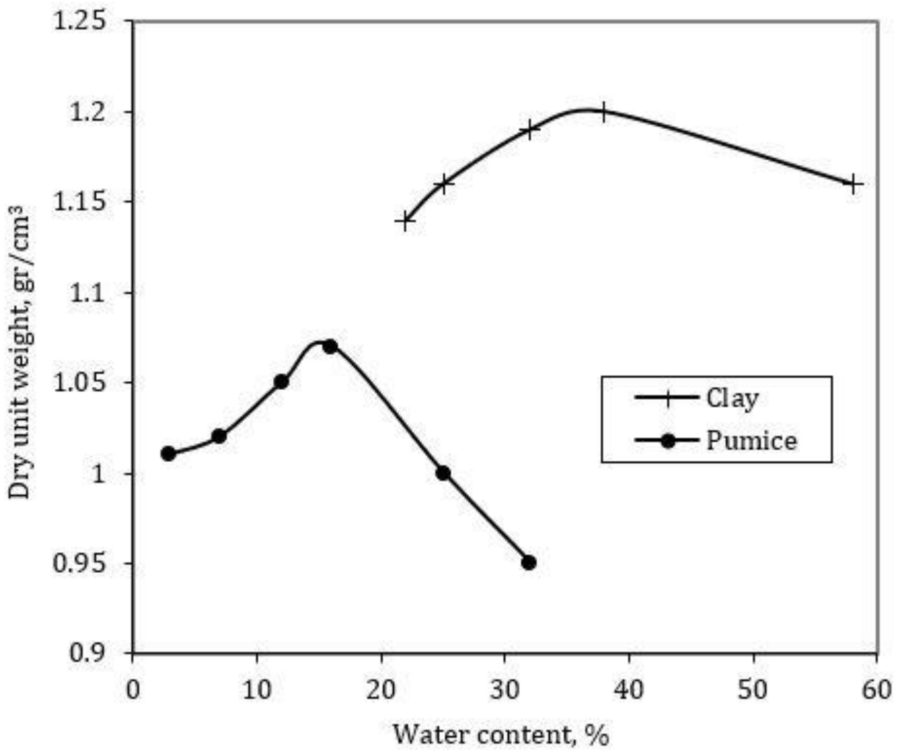
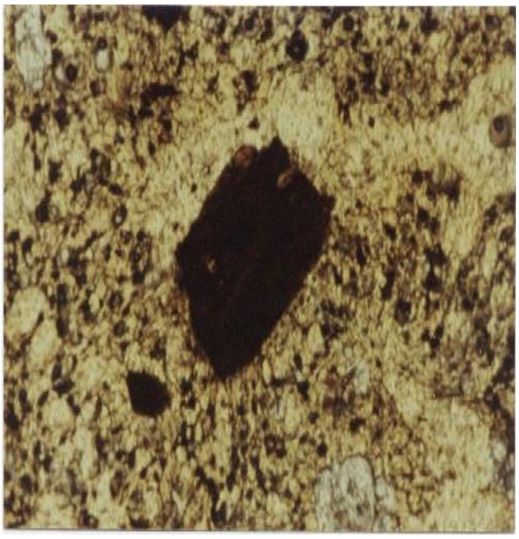


Figure 1. Standard compaction test results of clay and pumice.

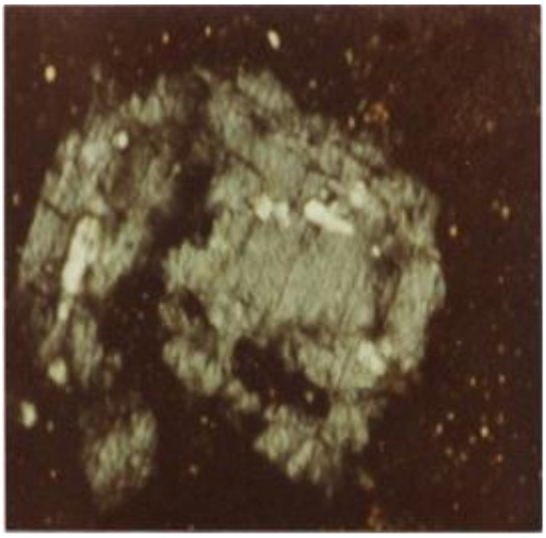
Table 1. Physical and index properties of used materials [18].

Properties	Clay	Additive material
Gravel, (%)	0	-
Sand, (%)	0	-
Silt, (%)	42	-
Clay, (%)	58	-
Liquid limit (LL), (%)	126	35
Plastic limit (PL), (%)	47	0
Plasticity index (PI), (%)	79	0
Shrinkage limit, (%)	37	7
Natural water content, (%)	-	25-30
Max. dry unit volume weight (γ_{dmax}), (gr/cm^3)	1.19	1.07
Optimum water content (W_{opt}), (%)	38	16
Grain unit volume weight, (gr/cm^3)	1.94	1.22
Color	Dark grey	Grey
Soil Classification	CH	Pumice

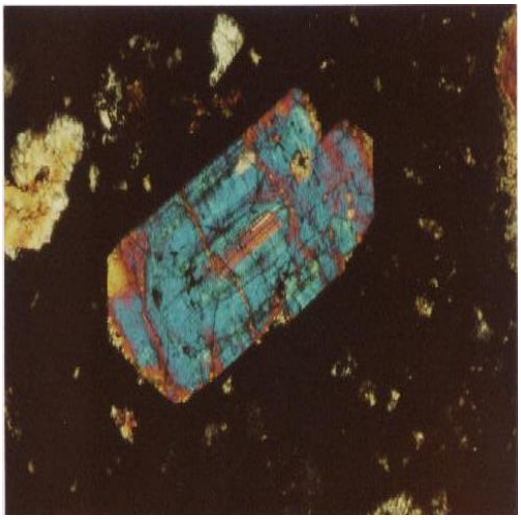
After examining the results in Table 1, the hydrometer readings show that the soil sample occurred from 58% clay and 42% silt. The liquid limit is 126%, the plastic limit is 47%, and the plasticity index is 79%, classifying the soil sample as high plasticity clay (CH) in the Unified Soil Classification System. The pumice, which will be used as an additive material, does not exhibit plastic properties. Its liquid limit is 35%, natural water content is 25-30%, and its grain unit volume weight is 1.22 g/cm^3. The pumice used as an additive material was analyzed by thinning the samples to 30 microns using abrasive powders in the thin section laboratory. Photographs were captured using a polarizing microscope, and the corresponding images are located in Figure 2.



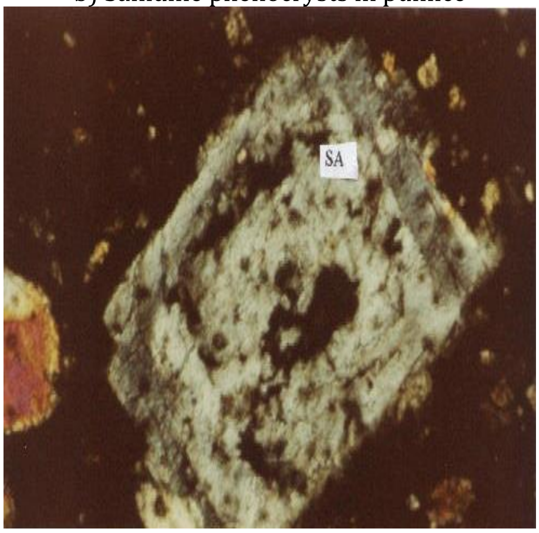
a) Opaque minerals in pumice



b) Sanidine phenocrysts in pumice



c) Pyroxene phenocrysts in pumice



d) Zoned feldspar crystal in pumice

Figure 2. Polarizing microscope images [18].

Based on microscopic analysis, it was found that pumice has a porphyritic texture and a holohyaline structure. It contains sanidine, pyroxene, biotite phenocrysts, and opaque minerals. Pumice is a volcanic material produced by explosive volcanism. The large crystals (phenocrysts) in the pumice show that the magma cooled in two stages. The phenocrysts formed during slow cooling, whereas the amorphous substances formed during rapid cooling [18]. The mineral structures of the samples were analyzed using X-ray analysis, and the findings are detailed in Table 2.

Table 2. Results of mineralogical analysis for used materials.

Materials	Minerals
Clay	Montmorillonite, kaolin, a few illite, quartz, feldspar, and a few mixed-layer clay minerals.
Pumice	Feldpar, opal-CT, quartz, mica group, amphibole group.

2.2. The tests of clay–pumice mixture samples

Unconfined compressive strength tests were conducted based on the optimum water content and maximum dry unit volume weight conditions determined from standard compaction tests, according to ASTM D 2166 [19] standards. The experiments utilized samples passing through the No.40 sieve. The prepared samples were placed in a cylinder that could be divided into two at a time, at the maximum dry unit volume weight and optimum water content, and compressed under the press. Prepared samples were compressed under pressure in one go at the maximum dry unit weight and optimum water content. Care was taken not to change the water content while the samples were compressed into the cylinder. The cylinder in which the sample is compressed is 38 mm in diameter and 76 mm in height. The samples were prepared with a Height/Diameter ratio between 2-2.5. The weight of the samples removed from the cylinder was verified, and then these samples were placed in the free-pressure device and loaded at a speed of 0.5 mm/min. The highest vertical stress is defined as the unconfined compressive strength of soil (qu).

Swelling pressure values of the prepared mixtures were determined by the constant volume oedometer test method ASTM D 4546 [20]. The mixtures were placed in the oedometer ring and compressed to the maximum dry unit volume weight and optimum water content. The oedometer ring is 71.5 mm in diameter and 17 mm in height. Necessary care was taken to ensure that the water content of the samples did not change during the compression of the sample into the ring. The samples squeezed into the ring were placed in the oedometer cell. The oedometer cell is filled with water. Thus, the swelling process of the samples started. Once the samples began to swell, loading was performed to maintain constant sample volumes. The experiment was terminated after the oedometer deformation clock stopped ticking. Then, the samples taken out of the oedometer cell were dried in an oven and weighed to examine the water content change. The final pressure applied to the samples when the experiments were terminated was determined as the swelling pressure (Ps).

3. Results

To assess the impact of pumice on clay, several tests are conducted, including the liquid limit, plastic limit, standard compaction, unconfined compression, and swelling tests. In Standard compaction tests, clay and pumice samples passing from sieve No. 4 are used. In the liquid limit, plastic limit, unconfined compression, and swelling tests, clay and pumice samples passing from sieve No. 40 are used. Pumice is combined with clay at weight ratios of 10%, 15%, 20%, 30%, 40%, and 50% in the tests. The results of the tests can be found in Table 3.

Table 3 shows that as the amount of pumice in the mixture increases, the liquid and plastic limits of the mixture decrease. As the amount of pumice in the mixture increases, the maximum dry unit volume weight increases but the optimum water content decreases. While it is observed that the unconfined compressive strength is lower in pure pumice samples, it is observed that the unconfined compressive strength increases in pumice-clay mixture samples. However, the unconfined compressive strength of pumice-clay mixtures decreases again for pumice ratios of 40% and more. When the swelling pressures are examined, it is seen that the swelling pressure decreases while the amount of pumice increases. When 10% pumice by weight was added, there was a 45% increase in unconfined compressive strength. There was an 8% decrease in the swelling pressure of the mixture to which 10% pumice by weight was added, compared to the pure clay sample.

Table 3. Results of liquid limit, plastic limit, standard compaction, unconfined compression, and swelling tests.

Tests Samples	LL (%)	PL (%)	PI (%)	γ_{dmax} (gr/cm^3)	$W_{opt.}$ (%)	q_u (kg/cm^2)	Ps (kg/cm^2)
Clay (C)	126	47	79	1.19	38	2.06	3.10
Pumice (P)	35	-	-	1.07	16	0.54	0
90% C+10%P	102	38	64	1.23	34	3.00	2.85
85% C+15%P	96	35	61	1.24	32	3.60	2.75
80% C+20%P	82	34	48	1.26	31	3.70	2.50
70% C+30%P	72	28	44	1.36	28	4.44	2.25
60% C+40%P	72	28	44	1.42	25	4.00	2.25
50% C+50%P	66	27	39	1.46	27	3.50	2.00

4. Discussion

In this study, where the effect of pumice on the engineering properties of clay was investigated, first consistency limit tests were carried out. The impact of the pumice amount on the liquid limit, plastic limit, and plasticity index of clay can be seen in Figure 3. As the ratio of pumice mixed with clay increased, the liquid limit, plastic limit, and plasticity index decreased. Adding fly ash to clay reduces the liquid limit [21]. Mixing fly ash into the soil may reduce the grain surface area of the soil, reducing the need for water and, as a result, reducing the plasticity of the soil [22]. The decrease in the liquid limit can be explained by the reduction in the thickness of the clay's diffuse layer and the increase in shear resistance at the particle level [23].

When pumice is mixed with clay, the change in unconfined compressive strength and swelling pressure with increasing pumice ratio can be seen in Figure 4. As seen in Figure 4, increasing the amount of pumice increased the unconfined compressive strength of the clay. The highest unconfined compressive strength was achieved when 30% pumice was mixed with clay. When the amount of pumice in the mixture was more than 30%, a decrease in unconfined compressive strength was observed. It is seen that as the pumice ratio in the mixture increases, the swelling pressure of the clay decreases.

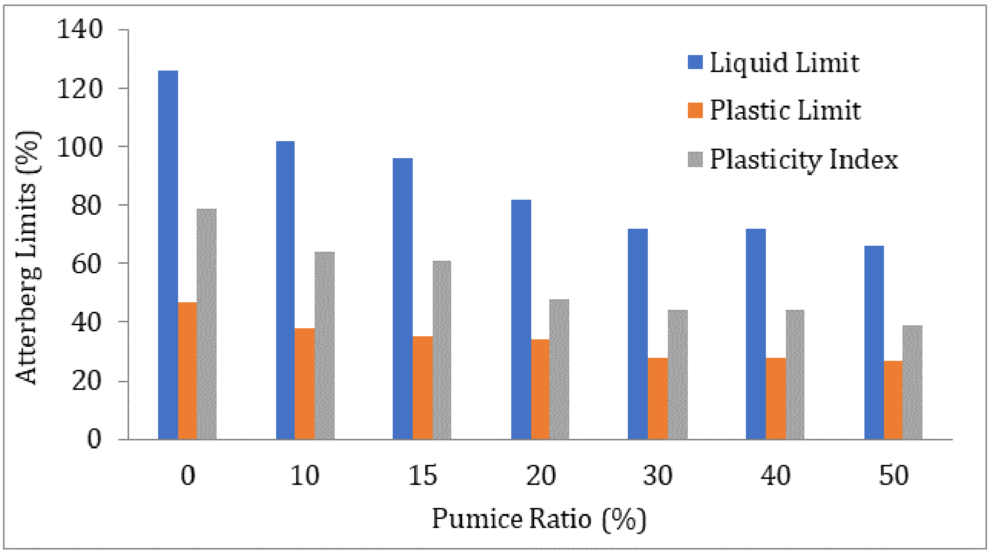


Figure 3. The effect of pumice ratio on the liquid limit, plastic limit, and plasticity index of clay.

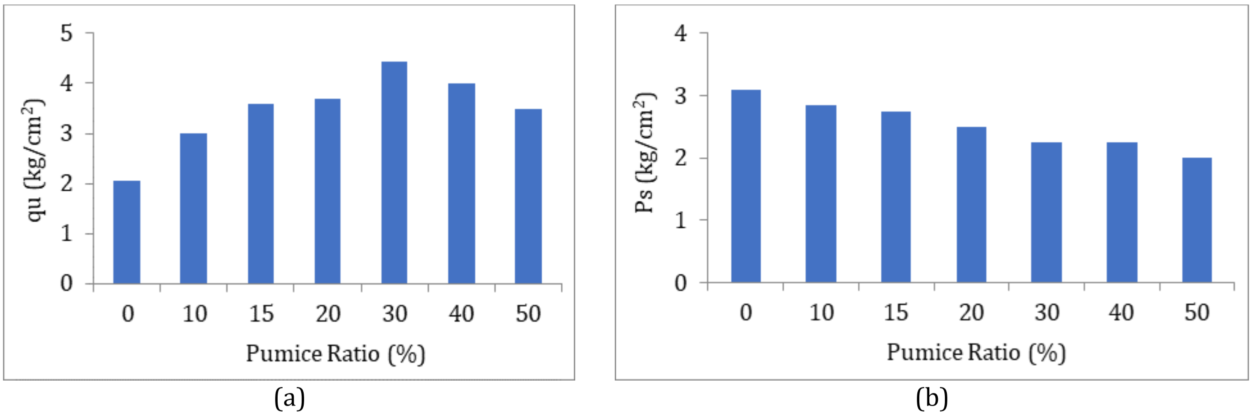


Figure 4. The effect of pumice ratio on clay: a) unconfined compressive strength and b) swelling pressure.

When studies on swelling are examined, it is known that the mineral structure of clay is very effective in swelling. The clay used in the study contains montmorillonite minerals. Montmorillonite is the mineral that causes the highest swelling pressure [24]. When stabilization materials are added to clay soil, two types of chemical reactions occur: colloidal and pozzolanic. These reactions can occur immediately or after a long period of mixing the additives with the clay soil. Unlike pozzolanic and colloidal reactions, carbonation is an undesirable process that harms stabilization [25-27].

There are three important stages in the process of improving the engineering properties of the soil with additives. These are the drying, modification, and stabilization stages. In the initial phase, the water content of clay soil diminishes rapidly due to the chemical reaction occurring among water and additives. In the second stage, plasticity, swelling, and shrinkage properties decrease. The third stage is to create a long-term impact on the properties of clay soil. These effects include long-term durability, consistent reduction in plasticity and shrinkage, resistance to swelling, warping, and prolonged wetting [28].

Çimen [29] demonstrated by laboratory and field experiments that waste pumice can be used in stabilizing clay soil. The recommended pumice mixture amount for Eşen clay (LL=108%, PL=38%, PI=70%) is 25-30%. Çimen et al. [30] investigated whether pumice-added clay samples could be used in subbase applications by performing California Bearing Capacity (CBR) tests. They suggested that using pumice for stabilizing clayey subgrades has economic, environmental, and engineering benefits. Locally available pumice has little commercial value. Because it is readily available, the transportation costs involved in using this resource are minimal. Çimen [31,32] investigated the consolidation behavior of pumice. In the consolidation tests performed by adding water to the oedometer cell at different loading stages, it was observed that applying water at the beginning of the test increased the amount of compaction. The ideal ratio of pumice to reduce the swelling pressure and settlement amount of compressed clay is 20-30%.

5. Conclusion

The following results are obtained from an experimental study with compacted clay-pumice mixture samples:

1- Liquid limit, plastic limit, and plasticity index decrease with increasing pumice ratio because pumice is a non-plastic material.

2- From standard compaction tests performed by adding varying amounts of pumice to clay, it is determined that maximum unit weight increases and optimum water content decreases with increasing pumice ratio.

3- From unconfined compression tests performed on clay-pumice mixture samples, it is determined that unconfined compressive strength increases until the pumice ratio is up to 30% while pumice additive ratios of 40-50% unconfined compressive strength decrease.

4- Adding pumice to the clay reduced the swelling pressure. As the amount of pumice increases, the swelling pressure decreases.

5- When the swelling pressure and unconfined compressive strength test results were evaluated together, it was determined that pumice could be used at a rate of 30% in stabilizing high-plasticity clay soil.

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Author contributions

Ömür Çimen: Experiment, Methodology, Conceptualization, Writing-Reviewing and Editing.
Sıddıka Nilay Keskin: Conceptualization, Methodology.

Conflicts of interest

The authors declare no conflicts of interest.

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