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A laboratory study on the liquid limits of cohesive soils improved with rice hush ash

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Abstract

Rice husk is a by-product of the rice milling process. About one hundred million tons of rice husks are produced annually worldwide. To reduce the waste volume, rice husk is burned as fuel in rice drying ovens, the combustion effect evaporates the organic compounds and water of the rice husk, leaving about 20% of the mass as rice husk ash. Rice husk ash has a pozzolanic effect and can be used as an additive in concrete. In addition, the improvement of soils with the addition of rice husk ash and lime has been investigated in various studies. Consistency limits are the water content values of cohesive soils where behaviour changes from liquid to plastic or plastic to solid. These values significantly affect the mechanical behaviour of soils. In this study, the consistency limits of soils improved with rice husk ash, an organic pozzolanic waste product, were investigated by laboratory studies.

1. Introduction

Any structure transfers the superstructure loads to the ground through foundations. If the ground has sufficient bearing capacity, it will be able to meet the loads coming from the superstructure without any problems. However, in some cases, the foundation soils may not have enough strength to withstand these loads from the superstructure. In such cases, it is necessary to carry out a number of ground improvement to make the soils sufficient in terms of bearing capacity.

Rice husk is an organic waste product resulting from the removal of the grains of rice (Figure 1). Rice husk ash, one of the natural pozzolanic additives for concrete, is obtained by burning rice husks [1]. As can be seen in Table 1, rice husk ash contains high amount of silicon oxide [2]. In this study, the use of rice husk ash, which is an organic waste product having pozzolanic character, in soil improvement works will be examined.

Table 1. Content of rice husk ash

Constituents	Rice husk ash (%)
SiO_2	89.18
Al_2O_3	1.75
Fe_2O_3	0.78
CaO	1.29
MgO	0.64
K_2O	1.38
Weight loss after burning	2.05

Figure 1. Rice husk ash

2. Material and Method

Consistency limits are the limits of water content used to describe soil behavior. If too much water is given to the cohesive soil, it behaves as liquid, in this case it has no shear resistance. If the soil is left to dry, it gains a certain shear resistance. The water content of the soil at this time of transition is called the liquid limit [3]. The liquid limit in this context is defined as the water content of the soil at the moment when it changes from a plastic consistency to a flowing form. The liquid limit can be estimated with two different laboratory tests namely Atterberg Limits Test (Casagrande test) or fall cone test. Within the scope of this study, liquid limit values were obtained by the Casagrande method.

In Casagrande test, firstly, cohesive soil samples are mixed with water and a homogeneous mixture is formed as shown in Figure 2. Sample is placed in the plate of the Casagrande instrument and its surface is leveled parallel to the base with the help (Figure 3). With the help of the flattened specimen grooving knife, a 2 mm wide cavity is opened from top to bottom as in Figure 4. The arm of the Casagrande tool is dropped from a height of 1 cm at a rate of 2 revolutions per second. As soon as the length of the opened cavity is closed by approximately 13 mm, the experiment is finished and the number of strokes is noted (Figure 5). A quantity of sample is taken into the aluminum container and the water content is determined. The test is repeated 5 more times using the same sample while increasing the water content. At the end of the test, a graph is drawn and the water content corresponding to 25 hits in the graphs is considered as the liquid limit of the sample used.

Figure 2. Soil sample

Figure 3. Placed soil sample

Figure 4. Soil sample to ready for test

Figure 5. Soil sample to end of test

In this study, firstly, a liquid limit test was carried out on the soil sample formed by using 50% by weight of clay and sand. Then, 10% by weight of rice husk ash was added on the same sample and the experiment was repeated and the results were presented.

2.1. Literature review

Aygün [1], carried out a soil improvement study by adding lime and rice husk ash to a silty soil. Within the scope of this study, firstly, the geotechnical properties of the soil sample were determined. Then, the soil sample, whose geotechnical properties were determined, was improved by using lime, rice husk ash and lime + rice husk ash. For soil improvement, 5% lime, 5%, 10%, 15%, 20% rice husk ash and their mixture combinations were added to the ground. Within the scope of this study, compaction, CBR and unconfined pressure tests were applied on the test samples. As a result of the compaction tests, it was observed that while the instantaneous undrained shear strength value was 30 kPa with the addition of 5% lime to the natural soil sample, it reached 86 kPa at the end of the 28-day curing period. If 20% rice husk ash was added to the natural soil sample, the instantaneous undrained shear strength value increased from 30 kPa to 48 kPa after 28 days of curing. Although there was some increase with the addition of rice husk ash alone to the ground, it was not significant. In the case of adding 5% lime + 20% rice husk ash to the natural soil sample, the instantaneous undrained shear strength value increased from 30 kPa to 186 kPa after 28 days of curing. As a result of the experimental studies, it was observed that the undrained shear strength values of the soil increased with the curing time. As a result of CBR experiments, free swelling and CBR values were examined. While the swelling value of the natural soil sample was 1.45 cm, the swelling value decreased to 0.03 cm after adding 5% lime to the ground and curing for 28 days. Likewise, the swelling values decreased with the addition of rice husk ash to the soil. While the CBR value of the natural soil sample was 6% at the end of the 28-day curing period, this value increased to 33% after the addition of 5% lime and the 28-day curing period. As a result of the CBR experiments, the CBR value for the natural sample was 6%, while this value was 20% as a result of the addition of rice husk. The greatest increase in CBR value was realized with the addition of lime and rice husk ash to the soil. As a result of permeability tests, it was observed that a slight decrease in permeability occurred with the addition of lime to the soil. If rice husk ash was added, the permeability of the soil increased. The permeability decreased when the two additives were added together. As a result of the experiments carried out within the scope of the study, it was observed that the physical properties of the soil improved with the addition of lime and rice husk ash together or separately.

Muntohar et al. [2], made soil improvement studies by adding rice husk ash, lime and waste plastic fiber in different proportions to silty soils. In the studies carried out in this context, some experiments were carried out by adding waste plastic fiber in different proportions to a mixture of 12% lime first, then 12% lime + 12% rice husk ash and 12% lime + 12% rice husk ash. As a result of these experiments, it was observed that lime and rice husk ash mixtures increased the compressive and tensile strength of the soil by 4 or 5 times, respectively, the inclusion of plastic waste fibers played an important role in increasing the tensile strength and strength ratio of the stabilized soil, and the pressure increased as the curing age increased. It was concluded that the resistance increased even more.

Çelik [4], investigated the fluidity, rheological, mechanical and stability properties of cement-based grout mixtures with rice husk ash added in his study. The experiments were carried out on 135 cylindrical samples and fifteen different mixtures prepared in three different water/binder ratios and various ratios of rice husk ash. The fluidity, plastic viscosity, apparent viscosity and cohesion properties of the prepared samples were investigated in the first part of the study. Subsequently, uniaxial unconfined compressive strength, amount of segregation and fracture criterion during axial loading were evaluated in the second part of the study. In the second section, it was observed that the mixing ratios were kept constant as in the first section and 20% by weight was mixed with a clay soil. The mixtures were cured at room conditions for 3, 7 and 28 days. With these tests, the unconfined compressive strength, elastic modulus values and settlement rates as a result of segregation were observed. Experiment results showed that rice husk ash and cement additive had a significant effect on the rheological, fluidity, unconfined compressive strength and stability properties of soils. The unconfined compressive strengths for all mixtures were found to be in acceptable ranges, remaining above 1 MPa and below 5% precipitation.

Basha et al. [5], investigated the improvement potential of residual soil soils by adding rice husk ash and cement at different rates in their studies. In this context, the compaction, strength and X-ray diffraction properties of the soil were evaluated. As a result of the tests, they observed that both cement and rice husk ash reduced the plasticity of the soil. In addition, it is understood from the test results that the addition of rice husk ash and cement mixtures to the soil in optimum proportions provides a noticeable increase in mechanical properties.

Brooks [6], observed the effect of rice husk ash in his laboratory experiments on mixtures of high plasticity clay and rice husk ash in different proportions. His C.B.R. and as a result of unconfined compressive stress experiments, the optimum rice husk ash ratio was calculated as 12% by weight. The clay-rice husk ash mixture, in which 12% by weight rice husk ash is used, provides a 97% increase in the unconfined compressive stress, while this ratio is C.B.R. was 47% in the test.

Behak [7], examined the effects of lime and rice husk ash on soil improvement studies. In this context, stabilization studies were carried out by applying combinations of rice husk ash and lime on sandy soils. In the experiments, it was observed that cementitious compounds were formed in soil mixtures containing rice husk ash and lime in different proportions. Unconfined compressive strength tests were carried out on soils treated with rice husk ash and lime. The results showed improvement in strength properties for all studied rice husk ash and lime contents and time periods. All soil samples produced as a result of the experiments were defined as modified rather than stabilized.

Liu et al. [8], investigated the cementous material lime and rice husk ash and its use on expansive soil. In the study, lime and rice husk ash mixtures were used in different ratios and combinations. The swelling test, consolidation test, unconfined compression test, direct shear test, and so on were applied to the soil samples obtained. In addition, the samples obtained were kept in curing for 7, 14, 28 and 56 days. With the increase in rice husk ash-lime content and curing time, the deformation properties such as swelling potential, swelling pressure, compaction index, crack amount and the thinness of the expanding soil significantly decrease; meanwhile, strength properties including unlimited compressive strength, cohesion and internal friction angle were observed to be significantly improved. Considering the engineering performance and cost, a 15% mixing ratio and an initial water content of 1.2 times the optimum moisture content were recommended by the researcher to stabilize the expanded soil.

Gülen and Kılıç [9], investigated the liquid and plastic limit values of fine-grained soils with different index properties by using Casagrande and falling cone experiments. In the experiments, they determined and compared the liquid and plastic limit values by using 300 and 80 grams falling cone tester and Casagrande instrument. As a result, they determined that the soil classifications made according to the consistency properties obtained with casagrande and falling cone may differ.

Komurlu and Çelik [10], determined the liquid limit values of different silt type soils for different void ratio values with Casagrande and cone penetrometer tests. According to the results they obtained, they observed that the void ratio of the soils had a significant effect on the liquid limit values. It has also been revealed as a result of the study that the cone penetration test is advantageous compared to the Casagrande test in order to minimize the void ratio effect and the operator dependent effect. According to the studies, the relationship between vacancy rate and liquid limit values differs according to the soils. For this reason, the use of a general relation for the estimation of the liquid limit value due to the change in void ratio was not recommended, instead they suggested testing the soils separately for the variation in void ratio.

Orhan et al. [11], compared the liquid limit values obtained by both the Casagrande method and the cone sinking method, using 13 natural soil samples with a liquid limit less than 100% taken from different regions of Ankara and Türkiye. As a result of this comparison, it was seen that the cone sinking method gave higher liquid limit values between 0.2% and 8.4% compared to the Casagrande method. In addition to the experiments carried out within the scope of this study, 73 data were compiled from previous studies in which the liquid limit was determined by both Casagrande and cone sinking methods for various purposes, and thus a total of 86 data were collected. When all of these data were evaluated together, it was seen that the liquid limit obtained by the cone sinking method was 0.2% to 22% higher than that obtained by the Casagrande method, except for a few samples.

Dipova [12], conducted a liquid limit test with the cone sinking method on a clayey soil sample and the test results were analyzed with statistical methods and the subject of determining the liquid limit with a single point was investigated. As a result of the experimental and statistical studies, 3 empirical equations were obtained for obtaining the liquid limit from the single point cone penetration test, and the equation "LL= W/(0.33*(P/20)+0.66)" gave the most reliable result. When a 4-point test is performed, the errors made in the experiment are less reflected in the Liquid Limit value since they are shared by drawing a trend line. However, since the mistakes made in the single point method will directly reflect on the Liquid Limit value, it has been found as a result of the study that more attention should be paid to all the details related to the experiment in the single point method.

3. Results

Based on the data obtained from the tests, liquid limit graph of the natural sample and the 10% by weight rice husk added sample are shown in Figure 6 and Figure 7.

As can be seen from these figures, liquid limit of the natural soil is found as approximately 20.8% whereas the liquid limit value of the soil sample with rice husk additive is obtained as 26.8%. Test results indicated that the plastic limit for the clayey soils with rice hush ash is higher compared to the unimproved soil. The water absorbtion capacity of the rice husk ash is significantly high causing the soil sample to behave liquid at relatively high-water content values. Plastic limit of the fine-grained soils is an important parameter defining how soils behave at different water contents. Therefore, this effect should be considered in ground improvement projects performed with using rice husk ash.

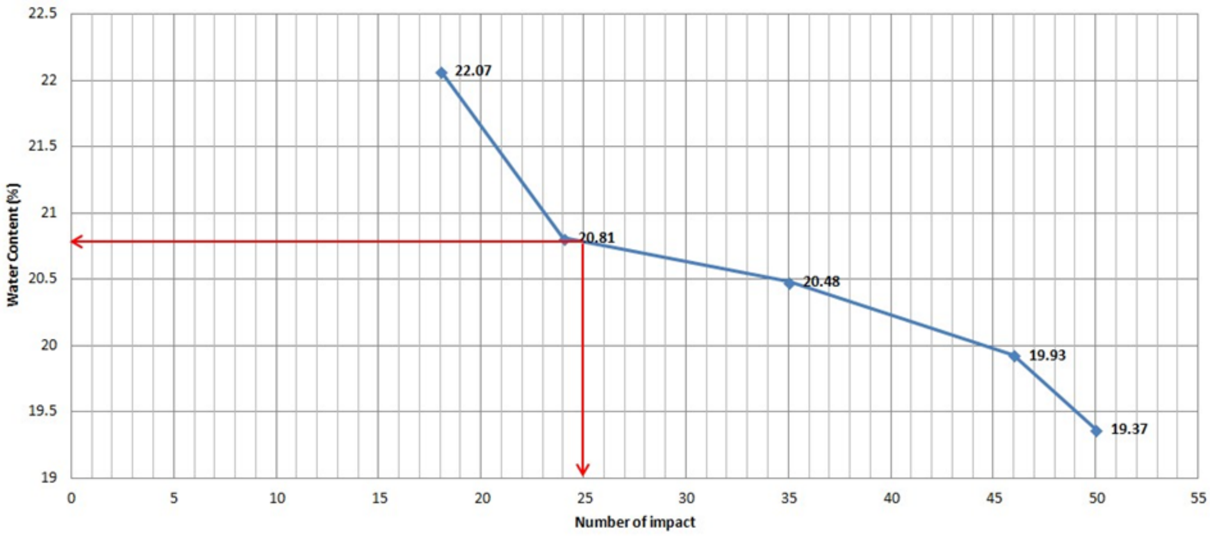

Figure 6. Casagrande test results for the soil without rice husk ash

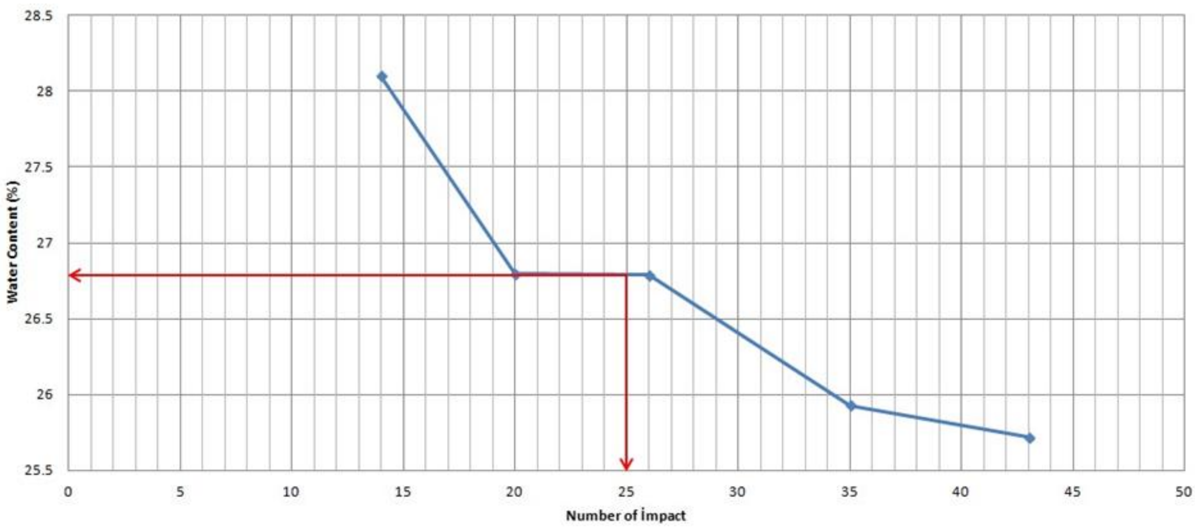

Figure 7. Casagrande test results for the soil with rice husk ash

4. Conclusion

In the liquid limit tests, it is seen that rice husk ash has a positive effect on the natural soil sample. Since rice husk ash contains more than 90% SiO_2, a pozzolanic effect was observed on soil samples. Using another material containing CaO to increase this pozzolanic effect will help to achieve better results. Since cementous material is formed as a result of the combination of SiO_2 and CaO materials, cementation will occur in the soil samples where these two materials are used and this leads to increase in the shear strength of cohesive soils.

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Author contributions

Abuzer Buluş Karakurt: Conceptualization, Methodology, Software **Özgür Lütfi Ertuğrul:** Data curation, Writing-Original draft preparation, Validation.

Conflicts of interest

The authors declare no conflicts of interest.

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