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Effect of Bone Ash and Rice Husk Ash on the Unconfined Compressive Strength of Silt Soil

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Abstract: This study investigated the soil stabilization potential of ash obtained from the calcination of cattle bones and ash produced by burning rice husks on silty soil. After the cattle bones were first crushed and burned, they were calcined at 800°C for 1 hour, allowed to cool, ground, and sieved with a sieve with a 75-micrometer opening to obtain bone ash (BA). To get rice husk ash (RHA), rice husks were burned, ground, and sieved through a 75-micrometer aperture. A silt soil sample taken from a depth of 3-4 meters from the center of Sakarya Province in Yenigün District of Adapazarı district was used to stabilize it. RHA was added as ground and unground, 10% by weight of the samples, BA as 7% by weight of the samples, and BA and RHA as 7% BA + 10% RHA by weight of the samples. Unconfined compressive strength (UCS) tests were performed for this research. The results showed that the UCS value increased with the addition of BA and RHA as the curing time increased for 7% BA, 7%BA+10% RHA, and 10% ground RHA, while 10% unground RHA lost strength. Caused Therefore, 7%BA+10%RHA can be used to increase the UCS value of the soil. Instead of allowing bones to be disposed of in the environment, calcined bone ash should be encouraged to sustain people's livelihood on stabilized soils.

Keywords: Sustainability, bone ash, rice husk ash, soil improvement, unconfined compressive strength

Öz: Bu çalışma, sığır kemiklerinin kalsinasyonundan elde edilen kül ile pirinç kabuğunun yakılmasıyla edielien külün siltli zeminin üzerinde zemin sabilizasyon potasiyelinin araştırılmasına odaklandı. Sığır kemikleri öncelikle parçalanarak yakıldıktan sonra 800°C'de 1 saat süreyle calsine edildi, soğumaya bırakıldı, öğütüldü ve kemik külü (BA) elde etmek için 75 mikrometre açıklığa sahip elek ile elendi. Pirinç kabuğu külü (RHA) elde etmek için pirinç kabukları yakıldı, öğütüldü ve 75 mikrometre açıklığa sahip elek ile elendi. Adapazarı ilçesi Yenigün Mahallesi'ndeki Sakarya İli merkezinden 3-4 metre derinlikten alınan silt zemin numunesi stabilize etmek için kullanıldı. RHA öğütülmüş ve öğütülmemiş olarak, numunelerin ağırlığına göre %10, BA, numunelerin ağırlığına göre %7 ve BA ile RHA numunelerin ağırlığına göre %7 BA+%10 RHA olarak eklenmiştir. Bu araştırma için Serbest basınç dayanımı (UCS) testleri yapıldı. Elde edilen sonuçlar, BA ve RHA'nın eklenmesiyle UCS değerinin, %7 BA, %7BA+%10 RHA ve %10 öğütülmüş RHA kürlenme süresi arttıkça artış gösterirken %10 öğütülmemiş RHA dayanım kaybına neden olmuştur. Bu nedenle, %7BA+%10 RHA zeminin UCS değerini artırmak için kullanılabilir. Kemiklerin çevreye atılmasına izin vermek yerine, stabilize topraklarda insanların geçimini sağlamak için kalsine edilmiş kemik külü üretimine girişilmesi teşvik edilmelidir.

Anahtar Kelimeler: Sürüdürülebilirlik, kemik külü, pirinç kabuğu külü, zemin iyileştirme, serbest basınç dayanımı

1. Introduction

Due to rapid urbanization and industrialization on a global scale, waste products diversify every year, and a considerable amount of waste is produced. It is essential to dispose of these waste materials without causing harmful effects on the environment. With the ever-growing environmental problems, the value of the additional material/additive to be used in ground improvement will increase even more if it is environmentally friendly and waste material. When viewed from this perspective, it is evident that rice husk ash (RHA) and animal bones, produced in large quantities in our country and worldwide, will pose a danger as industrial waste if they are not stored properly. Using these industrial (BA, RHA) wastes in ground improvement offers an acceptable environmentally friendly solution.

Bone is a variable tissue that performs many mechanical and biological functions. The main components of bone are amorphous forms of hydroxyapatite and calcium phosphate. The chemical and physical properties of bone are affected by age, nutrition, hormonal status, and diseases [1]. Bone ash (BA) is a whitish powdery residue left over from bone burning (calcination). Ash consists primarily of P_2O_5 and CaO in the form of calcium phosphate ($Ca_3(PO_4)_2$) or modified hydroxyapatite ($Ca_5(PO_4)_3OH$) [2]. The main chemical composition of natural bone is expressed in terms of calcium oxide and phosphorus pentaoxide; for cows, it is 32.1% and 28.3%, respectively.

Rice husk ash (RHA) is a byproduct of burning rice husks. Approximately 150 million tons of rice husks are produced annually worldwide [3-5]. RHA contains about 90% SiO_2 as a large amount of amorphous silica, and many studies are showing that it can improve the pore structure of concrete and effectively increase the strength and durability of concrete [4-6]. The study investigated the potential for reducing the amount of waste and improving the physical and chemical properties of the soil by using BA and RHA in soil improvement.

2. Material and Method

Adapazarı ground, whose properties are given in Table 1, will be used in the research. Depending on the soil samples' weight, They will be added as 7% BA, 10% RHA, and 7% BA + 10% RHA. The sample was taken from Adapazarı (Turkey), Yenigün District, at a depth of 3-4 m. The properties of the silty soil sample used in this study according to ASTM D4318 [7] are given in Table 1. The soil sample was classified as low plasticity silt (ML) according to USCS. Figure 1 shows the grain size distribution curve of the sample.

Table 1. Physical properties of the soil used in experimental study

Property	Value	Symbol and Unit
No 200#	89	FC (%)
Liquid limit	35	LL (%)
Plastic limit	25	PL (%)
Plasticity index	11	IP (%)
Specific gravity	2,692	G_s
Clay ratio	17	C (%)
Silt ratio	72	M (%)
Sand ratio	11	S (%)
Soil class: Low Plasticity Silt (ML)		

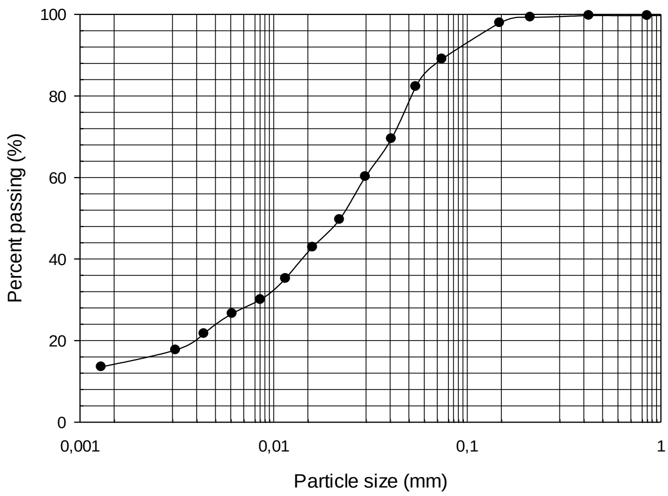

Figure 1. Grain-size distribution of samples used in the study.

First, the optimum water content and maximum dry unit weight of the samples prepared according to the determined mixtures were determined. After the proctor test was prepared at optimum water content, it was cured at 1, 7, and 28-day intervals, and UCS values were determined.

Rice husks are burned industrially in many countries. In addition to providing energy, the combustion process produces rice husk ash, a by-product rich in silica and can be used industrially. While the organic parts are burned away during the burning process, they are protected due to the silica structure specially stored in the shell [8]. For preliminary tests, the chemical properties of the cooled and ground burnt rice husk ash were examined using X-ray fluorescence Spectrometry (XRF) experiments, and the values were obtained in Table 2.

Table 2. Mineralogical properties of the RHA

Symbol	Element	Value(%)
SiO_2	Silicon dioxide	94.05
Al_2O_3	Alumina	0.55
Fe_2O_3	Iron oxide	0.31
MgO	Magnesium oxide	0.88
CaO	Quicklime	0.6
K_2O	Potassium oxide	0.28
Na_2O	Sodium oxide	1.07
SO_3	Sulfur trioxide	0.21
-	Other	2.05

For bone ash (BA), cattle bones taken from the Meat Complex affiliated with Kastamonu Municipality were burned uncontrollably. The chemical properties of BA used in the literature, and the chemical properties of bone ashes were first subjected to burning in the open air for our study, then calcined in the oven at 900 °C for 90 minutes. The ground, after cooling, is shown in Table 3. As can be seen from the table, there is plenty of calcium oxide (CaO) and phosphorus (P_2O_5) in the ash. While CaO increases mechanical strength by providing binding between soil grains, P_2O_5, which is also used as fertilizer in agriculture, will regulate the chemical properties (pH) of the soil.

Table 3. Mineralogical properties of the BA

Symbol	Element	Value (%) England BA	Japan BA	Used in the Study (BA)
CaO	Quicklime	41.7	41.1	54.99
P_2O_5	Phosphorus Pentoxide	57.1	55.9	46.26
SiO_2	Silicon dioxide	0,55	1,38	1.017
Al_2O_3	Alumina	0.33	1.30	< 0,0038
Fe_2O_3	Iron oxide	0.09	0.10	0.1293
Na_2O	Sodium oxide	0.03	0.04	< 0,014
K_2O	Potassium oxide	0.03	0.04	0.032
MgO	Magnesium oxide	0.20	0.21	< 0,0034
TiO_2	Titanium oxide	0.01	0.01	0.00722

In the study, samples will be prepared using BA and RHA materials, which are used to stabilize silty soil. For the stabilization of the soil, BA and RHA, which are not used in the literature, were used as optimum ratios of 7% and 10% of the soil weight, respectively [9–14]. 7% BA + 10% RHA of the soil weight was added.

The experimental study consists of 4 stages. The experimental research defined two materials, three different mixing ratios, and RHA as ground and unground variables. The experimental design using all variables is given in Table 4. First, to find the optimum water content of the mixtures, the optimum water content of the sieved soils was determined by the standard proctor test, considering the maximum grain diameter of the air-dry soil (Figure 2). Mixtures produced at optimum water contents (BA and RHA were thoroughly mixed with soil) were formed using the static compression method to form cylindrical samples with a diameter of 50 mm and a height of 100 mm. After the curing periods, the prepared samples were subjected to the unconfined compressive strength (UCS) test.

Table 4. Mixture properties and experimental design

Mix No.	(%) BA	(%) RHA
1 (Ref.)	0	0.
2	7 (Ground)	0
3	0	10 (Ground)
4	0	10 (Unpılverised)
5	7 (Ground)	10 (Ground)

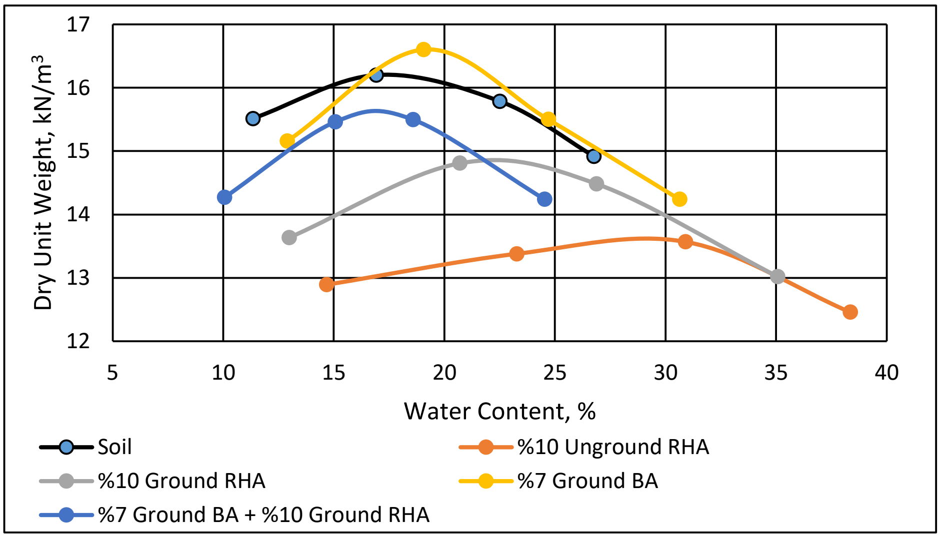

Figure 2. Optimum water content versus the dry unit weight of examples.

The silty soil taken from Adapazarı/Turkey city center was first air-dried in the laboratory environment. The air-dried sample was pulverized by hand. To prepare the samples homogeneously at the desired water content, it was sieved through the No.10 (2 mm) sieve with the maximum grain diameter to prevent lumping and re-move organic substances. The sieved soil sample was wetted by spraying deionized and deaired water for the desired degree of saturation in groups of 2 kg and mixed with the help of a sample preparation mixer. This process was repeated for each sample of different BA and RHA values. After the prepared samples, three different samples were taken from the other parts to check the WC, and it was confirmed that the water contents of the mixtures in all the prepared samples were equal within ± 0.5% evaporation/moisture change margin of error.

3. Result

The produced BA and RHA were thoroughly mixed with soil and then compacted using the static compaction method to form cylindrical samples with a diameter of 50 mm and a height of 100 mm. Before the UCS test, stabilized soil samples were wrapped with a thin film and cured under standard room conditions (20 ± 2 °C) for 1, 7, and 28 days. UCS testing was performed at a 1 mm/min loading rate using the Wykeham Farrance universal testing machine. Three replicates were performed for each mixture in the UCS test [15]. The strength values in Table 5 represent the average of three test results (q_u).

Table 5. Unconfined compressive strength test results of the soil

Mix No.		Curing time		
		1.Day q_u (kPa)	**7.Day q_u (kPa)**	**28. Day q_u (kPa)**
1	Ref.	57.53	57.53	57.53
2	%7 ground BA	54.96	55.89	70.96
3	%10 unground RHA	54.82	57.85	68.79
4	%10 ground RHA	34.13	37.14	40.44
5	%7 ground BA + %10 ground RHA	61.18	71.44	110.26

The maximum unconfined compressive strength values (qu) of each mixture according to their curing times are shown in Figure 3. Looking at Figure 3, qu strength increased as the curing time increased in all mixtures. In the mix where only unmilled rice husk was used, strength was lost compared to the reference sample value.

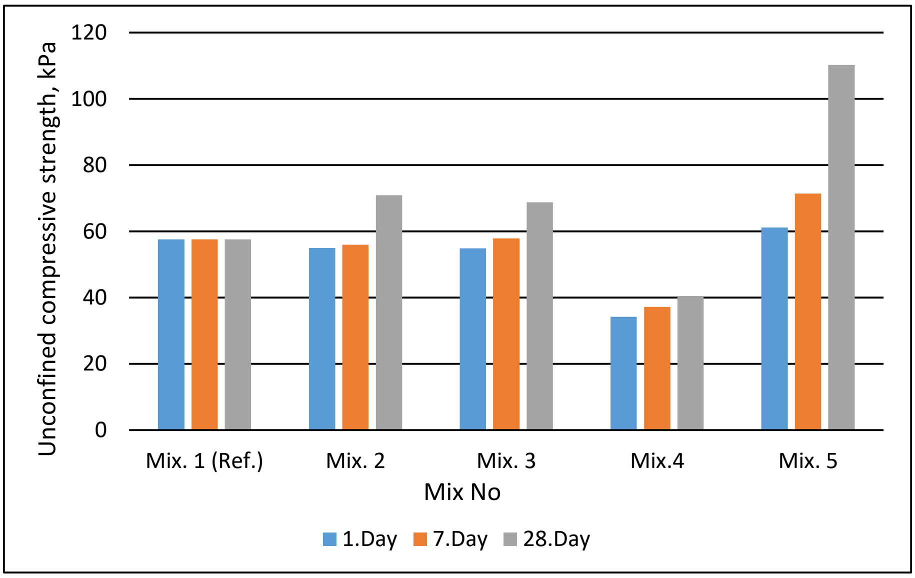

Figure 3. UCS versus curing time comparison

Unconfined compressive strengths were recorded as a function of vertical displacement up to the maximum value (Figure 4-7).

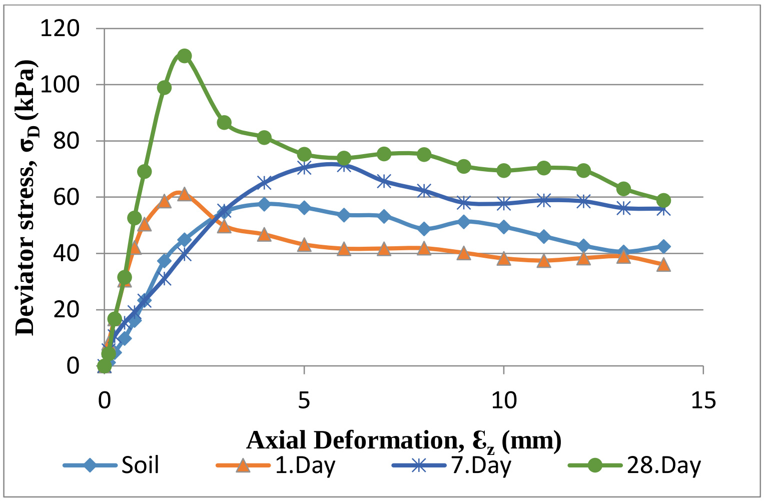

Figure 4. qu versus axial deformation relations under different curing times of %7 ground BA + %10 ground RHA mix

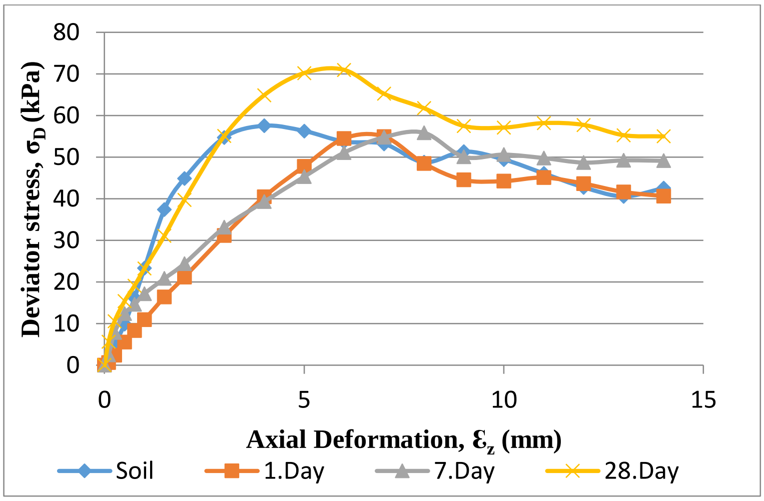

Figure 5. qu versus axial deformation relations under different curing times of %7 ground BA mix

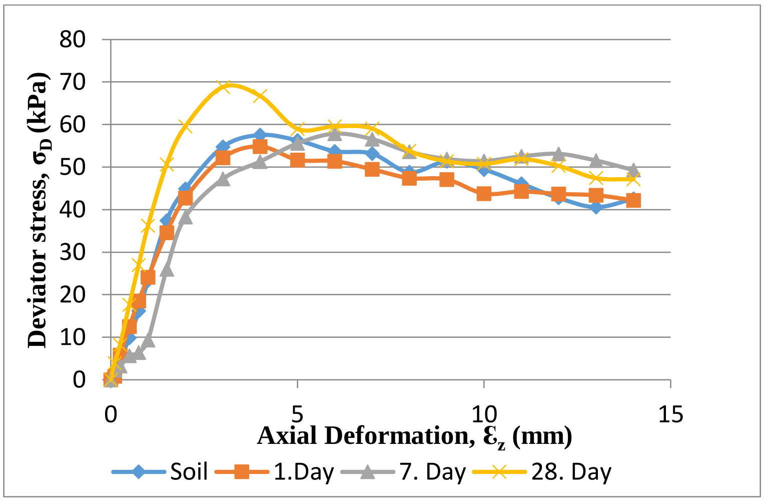

Figure 6. qu versus axial deformation relations under different curing times of %10 ground RHA mix

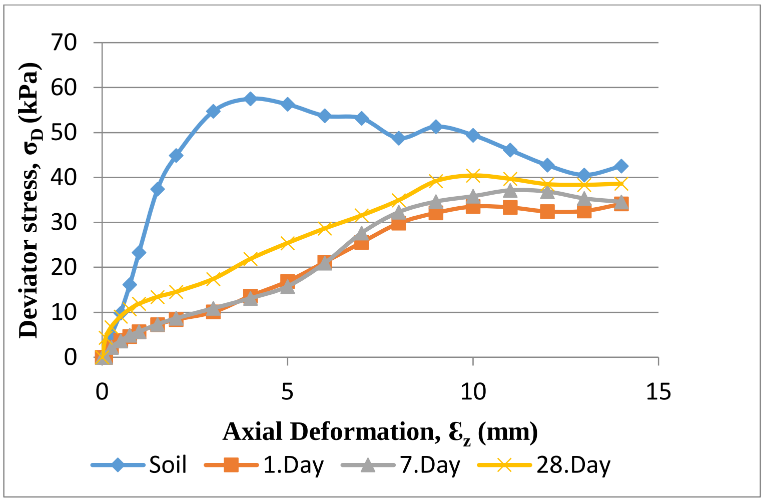

Figure 7. qu versus axial deformation relations under different curing times of %10 unground RHA mix

4. Discussion and Conclusion

There are very few studies in which BA and RHA are used together in studies aimed at improving the unconfined compressive strength of soils. In this context, a study was carried out to eliminate this deficiency in the literature and show the effect of reducing silty soils' compressive strength by using waste products.

One of the study's aims is to increase the unconfined compressive strength by mixing BA and RHA into silt soils. The ratios that provide the highest strength value were used in the literature studies in this context. Strength increases were measured by the unconfined compressive strength test, which has a simple experimental procedure, and it has been shown that this method, which can be performed in almost any soil laboratory, gives reliable results. The results obtained from the analyses can be listed as follows;

1. Although mixtures using ground 7% BA and 10% RHA caused a loss of strength in the short curing period, they provided a strength increase of 29.96% and 19.58%, respectively, in the long curing period.

2. Unmilled 10% RHA measured loss of strength at all curing times. The strength loss after 28 days of curing was measured as 29.70%.

3. In the samples where 7% BA + 10% RHA was used together, an increase in strength was detected at all curing periods. After the 28th day curing period, it achieved a strength increase of 91.66%.

As a result, it has been understood that BA and RHA increase strength when ground and used together. The high increase in strength in the 7% BA + 10% RHA mixture is attributed to the presence of CaO and SiO_2 in sufficient proportions. I recommend that future studies investigate the use of waste products together with alkalis.

Conflict of Interest

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Ethics Committee Approval

Ethics committee approval is not required.

Author Contribution

Conceptization, methodology, laboratory analyzes, writing draft, proof reading and editing: MUY.

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