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Impact of Rice Husk Ash on the Compaction Characteristics of Soil

Research Article

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ABSTRACT

Usually, the measurement of maximum dry density (MDD) and optimum moisture content (OMC) is important for assessing the quality control of the compacted fill or earthwork constructions as the compaction parameters. Rice husk ash (RHA), plentifully available in many rice-producing countries, can be used as a building material. This study mainly tries to investigate the effect of RHA on compaction features of sandy soil classified as A-2-4 or SM for soil stabilization. Nominal to a maximal dosage of RHA addition in the soil was considered for the experiments by the standard Proctor compaction tests. The result revealed that by increasing the amount of RHA in the soil, MDD was reduced and OMC increased significantly. It can be concluded that applying a soil-RHA combination is beneficial to soil improvement.

Keywords: *Soil stabilization, Optimum moisture content, Soil texture, Maximum dry density*

1. Introduction

Rice is one of the most consumed food items worldwide, and the annual global paddy production is predicted to be 519 million tons in 2022 (FAO, 2022). This indicates that 114.18 million tons of rice husk will be produced in that same year. Rice husk is an agrarian waste and a by-product of rice generated from paddy during the milling process (Singh, 2018), which is plentifully available in many rice-producing countries (Chandrasekhar et al., 2003). RHA forms when rice husk burns under controlled temperature (Babaso and Sharanagouda, 2017). More than 20 million tons of RHA are manufactured worldwide each year (Soltani et al., 2015; Alhassan, 2008). Due to the lack of its utilization, a considerable amount of RHA is discarded in abandoned areas, riversides, and open places, which causes environmental pollution (Pode, 2016) and poses a health hazard due to local air pollution. However, RHA is a supplementary

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cementitious material, and it comprises about 85-90% amorphous silica, a pozzolan that can react and partially replace Portland cement (Chopra and Siddique, 2015; Ramakrishnan, 2014). It can potentially be used as a construction material for various geotechnical applications. On the other side, cement is an essential binding element of concrete, but producing it is expensive, energy-extensive, diminishes natural resources, and produces a significant quantity of greenhouse gas emissions (Khan et al., 2012) that also cause environmental degradation, and severe pollution (Malhotra, 1999; Sabir et al., 2001; Worrell, 2001). Therefore, if the larger part of the RHA was used for ground improvement, it would have eliminated the need to dump RHA and reduced CO_2 emissions into the environment by reducing the necessity to produce cement. As a pozzolanic material, there are several benefits to using RHA in cement and concrete, such as increased strength and durability, lessen carbon dioxide emissions, etc. (Siddique and Khan, 2011).

RHA is not a brand-new substance for enhancing soil properties. All across the world, RHA has been used successfully with a wide range of soil types. Construction of building foundations, earth retaining structures, roads, highway embankments, footpaths, foundations, earth dams, and many more engineering constructions all require soil compaction (Ibrahim, 2018). Soil compactibility illustrates the mechanical behavior of soil, which is influenced by the compaction energy, water content, inherent bulk density, soil texture, organic matter, structural stability, and soluble salts (Thacker et al., 1994). Regarding the compactibility, combining RHA in the soil reduces the MDD and improves OMC (Ahmad et al., 2018; Kaur and Jha, 2016;). There are many pieces of research on soil compaction parameters (Basha et al., 2005; Behak, 2017; Bera and Ghosh, 2011; Boltz et al., 1998; Eberemu and Sada, 2013; Matteo et al., 2009; Nahar et al., 2021; Qu et al., 2014; Sridharan and Nagaraj, 2005). Still, very few studies have been conducted on the compactibility of the ground where a small amount of RHA was used. Thus, the current study attempts to understand the impacts of a lower to a higher amount of RHA on the compaction characteristic of soil.

2. Materials and Methods

2.1 Materials

Data from primary and secondary sources were both used in this investigation. Laboratory experiments were conducted to get the primary data. The testing specimens were made of soil and RHA. The soil sample was collected from the Handa area, Tsu City, Mie Prefecture, Japan. The soil sample is texturally composed of 89% sand, 9% silt, and 2% clay. According to the Unified Classification of Sandy soils by ASTM D-2487, the particular soil is well-graded sand with silt. The soil is also classified as Silty gravel and sand, A-2-4 type by the American Association of State Highway and Transportation Officials (AASHTO). The soil had a specific gravity of 2.74 g/cm^3. The liquid limit, plastic limit, and plasticity index of the soil were 37.52%, 28.97%, and 8.55%, respectively. In this investigation, RHA was generated through burning at temperatures between 650°C and 700°C. The RHA consisted of particles of sizes ranging from 0.001 to 0.3 μm, which were given by the Make Integrated Technology (MIT) Company, situated in Osaka, Japan. The specific gravity of RHA was 2.12 g/cm^3. The significant chemical properties of RHA were silica (91.1%), carbon dioxide (4.35%), potassium oxide (2.40%), and alumina (0.03%) (M.I.T., 2018). Available ordinary tap water in the laboratory was used in all of the specimens. Secondary data were used from the literature review as a supplement to primary data.

2.2 Mix Designs of Specimens

In this study, two mixed Groups of soil-RHA specimens were arranged, and the specimens mixing design ranged from a nominal to a maximal percentage of RHA amount of soil weight to comprehend how RHA affected the soil samples. Initially, soil addition with nominal RHA of 0.5%, 1.0%, and 1.5% was used for this investigation (considered as Group A). Later, data (where maximal dosages of RHA were taken) from another study (Nahar et al., 2021) was used to understand the compaction behavior of nominal to higher dosages of RHA in the soil. These data included the compactibility of 5%, 10%, and 15% RHA (which are ten times higher RHA amounts than that of Group A) with a similar type of soil (considered as Group B). Table 1 displays the mixing composition of the specimens.

Table 1 Investigated mixtures with indices

Mix Group	Mix design	Index
Group A	Natural soil	Control
	Soil + 0.5% RHA	S+0.5R
	Soil + 1.0% RHA	S+1.0R
	Soil + 1.5% RHA	S+1.5R
Group B	Soil + 5% RHA	S+5R
	Soil + 10% RHA	S+10R
	Soil + 15% RHA	S+15R

2.3 Laboratory Test

All laboratory experiments of this study were conducted at the International Environment Conservation Laboratory (IECL) at Mie University, Japan. The Standard Proctor compaction test was carried out in accordance with Japanese Industrial Standards (JIS-A-1210), to ascertain the MDD and OMC of natural soil and other soil-RHA combinations. The test was conducted using a 10 cm diameter cylindrical compaction mold that had a base and a collar, a 2.5 rammer mass, and a 30 cm falling height (Figure 1). The RHA mixed soil was compressed in the compaction mold in three layers, each receiving 25 blows.

Figure 1. Apparatus (Mold and Rammer)

Soil-RHA was mechanically blended thoroughly in a dry environment for each combination type. Subsequently, water contents were supplemented uniformly by hand mixing to obtain the desired moisture content (Figure 2). After removing the compressed specimen from the mold, samples were divided evenly into three layers.

Figure 2. Mixing water manually with air-dried soil to reach the expected water content

Then each layer of a sample was separated into nine parts from where the central part was taken as a sample for the oven-dry weight (Figure 3). Similar way, water was added repeatedly to get the maximum dry density and optimum water content.

Figure 3. Sample collection from the central part of a layer in a specimen

Thereafter, the dry and wet unit weights of each soil-RHA combination are computed to obtain the distinct range of dry density and water content values for each specimen. The collected data were plotted on X-axis representing the water content (%) and on Y-axis representing the dry density (g/cm^3). The plotted points were then connected which showed a curvilinear relationship known as the compaction curve, which indicated the OMC against MDD for each soil-RHA specimen. The OMC is the quantity of water that corresponds to the MDD value, which is the highest point on the compaction curve (Figure 4).

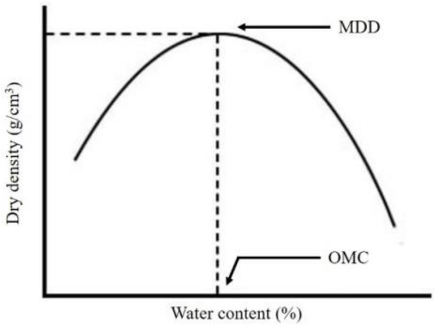

Figure 4. Schematic of soil compaction curve

3. Results and Discussions

The compaction curves of different soil-RHA specimens illustrate the association between dry density and soil water content. It is observed from the compaction curves of the test specimens that MDD and OMC followed a typical behavior (Figure 5). The compaction curves of Group A (S+0.5R, S+1.0R, and S+1.5R) specimens are more closely spaced than those of Group B (S+5R, S+10R, and S+15R) specimens because there is less variation in RHA between specimens in Group A and more variation in RHA between specimens in Group B.

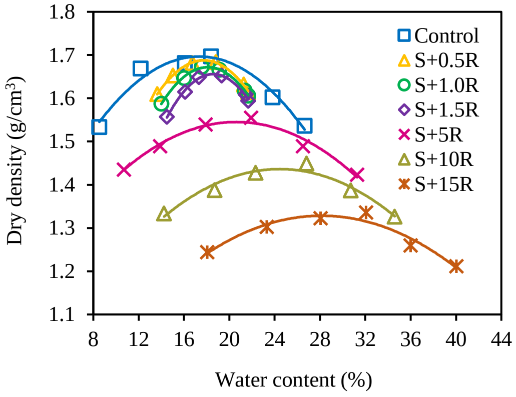

Figure 5. Compaction curves of control, Group A (S+0.5R, S+1.0R, and S+1.5R) and Group B (S+5R, S+10R, and S+15R) specimens

The variations of OMC of soil-RHA specimens are presented in Figure 6. The OMC of control was 17.5%. The figure illustrated that with increasing RHA amount, OMC increased significantly compared to the control specimen. The specimens in Group A (S+0.5R, S+1.0R, and S+1.5R) exhibited a slightly increasing tendency of OMC but the specimens in Group B (S+5R, S+10R, and S+15R) showed a significantly increasing tendency of OMC. After mixing the additional RHA with soil, the quantity of fine particles increases in the soil which needs more water for hydration (Eberemu and Sada, 2013). The rates of increase in OMC over the control were 1.4%, 4.0%, and 6.4%, respectively for the S+0.5R, S+1.0R, and S+1.5R specimens, whereas these rates were 14.2%, 37.1%, and 61.1%, respectively for S+5R, S+10R, and S+15R specimens (Table 2).

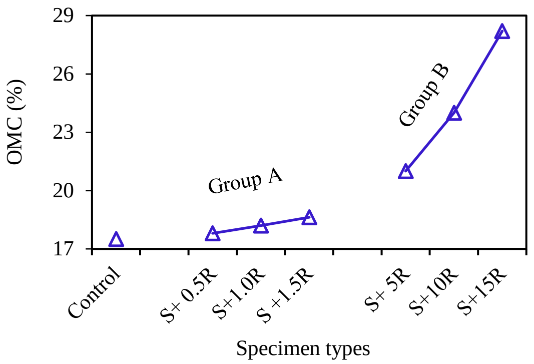

Figure 6. Variation of OMC of control, Group A (S+0.5R, S+1.0R, and S+1.5R), and Group B (S+5R, S+10R, and S+15R) specimens

Figure 7 presents the variations in MDD of soil-RHA admixtures. Untreated soil (control) had an MDD of 1.69 g/cm^3. According to the graph, MDD significantly decreased when soil RHA levels dropped in comparison to the control specimen. The specimens in Group A (S+0.5R, S+1.0R, and S+1.5R) exhibited a slight reduction in MDD in comparison to the natural soil, while the specimens in Group B (S+5R, S+10R, and S+15R) showed a significant drop in MDD. The MDD decreased as the increment of RHA content in the soil because RHA has a specific gravity (2.12 g/cm^3) that is

Table 2 Compaction features of control, Group A (S+0.5R, S+1.0R, and S+1.5R) and Group B (S+5R, S+10R, and S+15R) specimens. Data of Group B adopted from Nahar et al., (2021).

Mix group	Index	Optimum Moisture Content (OMC)		Maximum Dry Density (MDD)	
		OMC (%)	*Increase rate (%)	MDD (g/cm^3)	*Decrease rate (%)
	Control	17.5	-	1.696	-
Group A	S+ 0.5R	17.8	1.7	1.688	0.471
	S+1.0R	18.2	4.0	1.672	1.415
	S +1.5R	18.6	6.4	1.656	2.358
Group B	S+ 5R	20.0	14.2	1.545	8.903
	S+10R	24.0	37.1	1.436	15.330
	S+15R	28.2	61.1	1.334	21.344

* Note: Increase and decrease rates were calculated compared to the control specimens.

comparatively lower than natural soil's (2.74 g/cm^3). According to Osinubi and Katte (1997) and Nahar et al. (2021), RHA particles are replacing soil particles. The specimens S+0.5R, S+1.0R, and S+1.5R showed decrease rates of 0.47%, 1.41%, and 2.35%, respectively; in contrast, the specimens S+5R, S+10R, and S+15R showed reduction rates of 8.90%, 15.33%, and 21.34%, respectively (Table 2). The dry density of the soil tends to decline, indicating that less compaction energy is needed to achieve the MDD for a given specimen, hence lowering the cost of compaction (Muntohar and Hantoro, 2000; Eisazadeh et al., 2019).

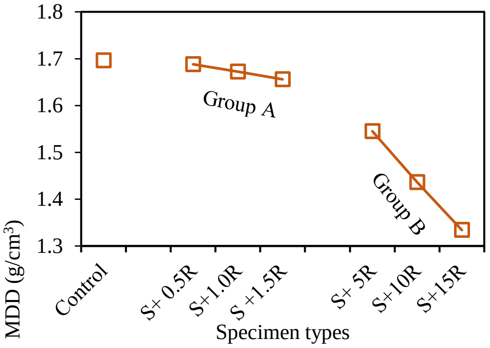

Figure 7. Variation of MDD of control, Group A (S+0.5R, S+1.0R, and S+1.5R), and Group B (S+5R, S+10R, and S+15R) specimens.

Furthermore, a greater percentage of RHA amount addition with soil results in a higher OMC and a lower MDD value of the specimens. The OMC and MDD trends in Group B specimens were significantly higher than those in Group A. Additional research also revealed this pattern (Alhassan, 2008; Ahmad et al., 2018; Basha et al., 2005; Qu et al., 2014; Kaur and Jha, 2016; Nahar et al., 2021).

4. Conclusions

This study investigated the effects of RHA on the compactibility of soil, and the results revealed that an extensive environmental pollutant, RHA can improve soil quality. The addition of RHA increased the OMC but diminished the MDD of the soil. The specimens of Group A (S+5R, S+10R, and S+15R) showed a greater increment in OMC and a slighter reduction in MDD compared to the specimens of Group B (S+0.5R, S+1.0R, and S+1.5R). Road projects and other ground development projects requiring large quantities of earth materials can benefit from the use of RHA waste combined with soil. Efficient utilization of waste materials can significantly reduce construction expenses and protect the environment.

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