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Geotechnical Properties of Clayey Soil Stabilized with Rice Husk and Cement

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Abstract

Rice husk (RH), as stabilizing element, can be both, cost effective and environmentally beneficial, because of its local abundance and for its ability to strengthen the soil in its original form. This paper investigates the effectiveness of using RH and cement as a stabilizing agent in the soft clayey soil. In this research, the clayey soil has been mixed with varying percentages of RH (5%, 10%, 15% and 20%) and at the same time, these samples have been further mixed with a fixed 2% cement content and all of them have been tested to analyze their influence on soil properties (specific gravity, Atterberg limits, linear shrinkage and shear strength). By dissecting the results, liquid limit and plastic limit values have increased and the plasticity index value has decreased, which, as a result, classified the soil as silt rather than clay. Moreover, the decrease of linear shrinkage value signified shrink resistance behavior of the altered soil. The direct shear testing has further established, the soil's high shear resistance characteristic by visualizing the increase of cohesion and angle of internal friction value. It can also be revealed that, the altercation of the clayey soil with 15% RH and 15% RH+2% cement might be feasible, cost effective and environmentally friendly in stabilizing the soil, as these two mixtures indicated the most promising improvements of the soil's geotechnical properties.

Keywords: Cement, clayey soil, direct shear test, rice husk, soil stabilization

Introduction

Soil stabilization is an engineering process of improving soil's core characteristics through various modification activity. This procedure is crucial for any project that demands the soil to be of certain standard in order to meet the end result of the engineers (DAS 2006). The modification procedure involves the addition of various modifier(s) with the soil in order to improve the index classification. Traditionally, two main stabilizing materials, namely cement and lime, were the first choice of many researchers and project managers for modifying and/or stabilizing the soil for their intended application. However, these materials became expensive with the cost of energy on the rise since 1970s and this often-made various development undertakings a money pit for the investors (NEVILLE 2012). The over-utilized building material, such as cement, while has advantageous effect in acting as a binding agent,

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at the same time it is environmentally unsound. For reference, during Portland cement manufacturing process, a substantial amount of CO_2 is being produced for every ton of cement production (Sear 2005).

The rapid increase in demand for new land has presented the society with unique challenges in fulfilling their infrastructural needs and various researches are being carried out for discovering new and sustainable ways of stabilizing the soil (Osinubi *et al*. 2012). As a result, many underdeveloped countries are not been able to construct their required infrastructures, specifically roads, railways, channel, irrigation system, pavement and bridges, in their rural sections of the lands, where the majority of their country's population and economy lies (Alhassan & Mustapha 2007). Some of these rural areas contain soil with less stability and resilience, for example, expansive soil, lateritic soil, organic soil, clayey soil, etc. Among those expansive soils, soft clay is characterized by a high water content, low strength, and significant deformation, making it unsuitable for use in building engineering. Due to these properties, soft clay presents challenges for construction, it is generally not suitable for use in construction engineering and often requiring specialized foundation techniques to ensure stability. At present, these low strength soft soils are being stabilized using the traditional additives (cement, lime, etc.) for various infrastructure projects. However, scientists are also focusing toward alternative materials that are widely available, namely waste elements, as potential modifiers for soil stabilization mean. The researchers have pointed out that most industrial by-products and/or agricultural wastes materials, such as rice husk ash, banana leaves ash, fly ash, saw dust ash, bean husks, sugarcane strew, cassava peel, bagasse ash, ground-nut-husk ash, wood and bamboo leaf ash, etc. are quite useful as stabilizing components, improving the geotechnical properties of the expansive soil (Amu & Adetuberu 2010; Bello *et al*. 2015; Nnochiri & Aderinlewo 2016; Nnochiri & Ogundipe 2016; Olowofeyeku *et al*. 2021; Agaiby *et al*. 2022; Sani *et al*. 2023). All the above researches focused on additives for its pozzolanic behavior, low cost, adaptability and environmental sustainability (Agarwal 1989; Kumar 1993; Nnochiri & Ogundipe 2016; Olowofoyeku *et al*. 2021; Agaiby *et al*. 2022). However, this ash usage has its own drawback related to toxic chemical emission through smoke produced by burning of the original materials. Therefore, this research paper aims to avoid the emission related issue by incorporating an original raw material, namely, rice husk to stabilize soft clayey soil.

Rice Husk (RH) is considerably cost effective, readily available and environmentally sustainable. Rice husk is produced at the time of milling process of rice. Bangladesh has the 3rd highest rice production in the entire world, which is around 39.3 million ton of rice produced last year. This huge rice production leads to a staggering 9.83 million ton of rice husk after milling process which is, globally, approximately 120 million ton. However, it is estimated that, on average, there could be 15% yield of rice husk during milling process with 82% silica content (KAMON & BERGADO 1991; SEAR 2005; SANI *et al*. 2023). Rice husk sample, which had been selected for this research, embodied around 66.14% SiO_2, 4.58% Al_2O_3 and 2.34% Fe_2O_3. Having a high silica characteristic makes the rice husk a very immune to organic disposal means. Silica is naturally found in rice husk in an amorphous form, rendering it a valuable pozzolanic material and at the same time, this silica reacts with the $Ca(OH)_2$ of the cement and produces a strong bond. Furthermore, similar bonding characteristic with the soil can be noticed because of rice husk's high specific surface (AGRAWAR 1989; KUMAR 1993; KIRAN & KIRAN, 2013; SARKAR *et al*. 2012; DORMOHAMADI & RAHIMNIA 2020). Moreover, rice husk is very lightly weighted and has enhanced insulation capability, local availability and less environmental impact. This will allow us to conserve the usage of our natural resources, as well as, reduce the formation of waste heaps through recycling. Thus, it can be used as an alternative aggregate. With these findings in mind, this research investigates the impact of rice husk and cement on the engineering properties of soft clayey soil.

Materials and Methods

Materials

Clayey soil, rice husk (RH), ordinary portland cement (OPC) and water are the main materials employed in this study. The clayey soil that was used in this research was nearly dark gray to light brown in color and was collected from Palli Bidyut, Savar area in Dhaka, Bangladesh, excavated from a depth of 1.2–2.0 m following the method of disturbed sampling. The basic engineering properties and grain size distribution curve of this specific soil are shown in Table 1 and Fig. 1 respectively. RH is collected from the Savar Rice Mill which is produced as agricultural waste. It is the hard protective coverings of rice grains which are separated from the grains during milling process. The ordinary portland cement is sourced from a local cement vendor of Savar, Dhaka. Lastly, required amount of water has been used to prepare the samples for various testing activities.

Table 1. The basic engineering properties of the studied clayey soil.

Moisture content	22.10%
Specific gravity	2.62
Liquid limit	47.52%
Plastic Limit	21.21%
Plasticity Index	26.31%
Linear Shrinkage	13.93%
Grain size analysis	
Sand	18.21%
Silt	41.22%
Clay	40.57%

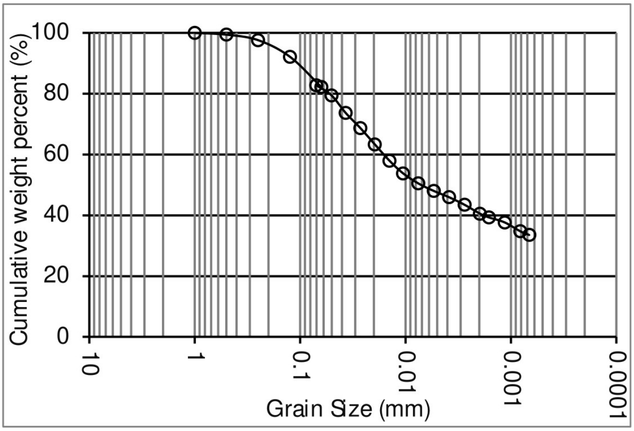

Fig. 1. Grain size distribution curve of the studied clayey soil.

Sample Preparation

The soil samples were divided into nine portions, each portion of the soil sample was mixed thoroughly with Rice Husk (Fig. 2) at different percentages, respectively, 0, 5, 10, 15 and 20%. These mixtures were later on again mixed with 2% of cement content comparable to the dry weight of the soil. The sample mixing percentages are given in Table 2. The soil with RH and Cement induced RH samples was then thoroughly mixed and keep in an air tight bag for 20-25 days to ensure a homogenous blend and decomposed.

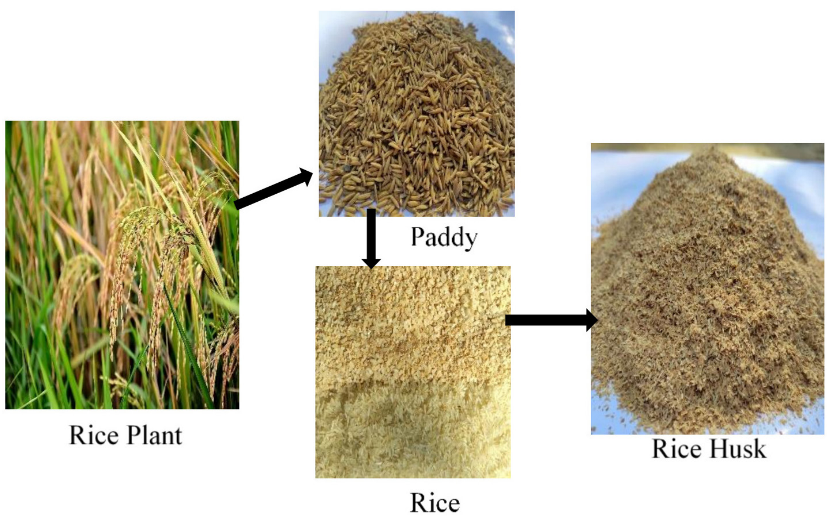

Fig. 2. Collected rice husk sample.

Table 2. Combination scheme of soil for rice husk (RH) and RH-Cement.

Sample	Percentage	Weightage of different materials		
		Clayey soil (gm)	Rice Husk (gm)	Cement (gm)
Soil	Pure soil	1000	-	
RH mixed samples	5%RH	950	50	
	10%RH	900	100	
	15%RH	850	150	
	20%RH	800	200	
Cement induced RH samples	5%RH+ 2%C	930	50	20
	10%RH+ 2%C	880	100	20
	15%RH+ 2%C	830	150	20
	20%RH+ 2%C	780	200	20

Methods

The geotechnical properties of the untreated soil and treated soil determined in accordance to ASTM (1974) and BS 1377 (1975). The basic properties (specific gravity, Atterberg limit and linear shrinkage) of both type of soils (untreated and treated soil) were conducted at the Engineering Lab, Department of Geological Sciences, Jahangirnagar University. The direct shear test was conducted at the Housing and Building Research Institute (HBRI), Mirpur, Dhaka 1216.

Results and Discussions

Basic Properties

A summary of the basic geotechnical properties such as specific gravity, Atterberg limits and linear shrinkage of all the tested samples is given in Table 3. The obtained specific gravity of the untreated soil is 2.62. However, after mixing the soil with different percentage of rice husk, the specific gravity gradually decreased and demonstrated a range of 2.54 to 2.35, from 5% RH mixed sample to 20% RH rich soils respectively. Due to the addition of 2% cement in each corresponding RH mixed soil, the specific gravity slightly increased than that of RH mixed soils but the ultimate trend is declining (Fig. 3).

Overall, it can be said that the specific gravity confirmed a greater drop in value, when only the RH mixed with samples and the results is consistent with that of SARKAR *et al.* (2012), OLOWOFOYEKU *et al.* (2021) and SANI *et al.* (2023).

In Atterberg limits test, it is found that the liquid limit of the soil steadily increased with the increase of RH content and cement induced RH samples (Fig. 4). The liquid limit value ranged from 49.83 to 56.14% for RH mixed samples, indicating an ultimate growth of 18.14% compared to untreated soil. Whereas, it is ranged between 48.42 to 53.51%, signifying a terminal growth of 12.61% for the cement induced RH samples. The plastic limit values are also increased of RH mixed and cement induced RH samples ranged between 24.29 to 31.72% and 27.63 to 34.13%, respectively (Fig. 5). It is also found that the plastic limit of the stabilized soil increased by 49.55% in 20% RH induced soil and 60.91% in cement induced 20% RH soil than that of the untreated soil.

Table 3. Basic geotechnical properties for RH mixed and cement induced RH samples.

Sample	Percentage	Specific gravity, Gs	Atterberg limit (%)			Linear Shrinkage
			Liquid Limit	Plastic Limit	Plasticity Index	
Soil	Pure soil	2.62	47.52	21.21	26.31	13.93
RH mixed samples	5%RH	2.54	49.83	24.29	25.54	12.42
	10%RH	2.43	52.12	27.28	24.84	11.54
	15%RH	2.39	54.23	29.78	24.45	11.14
	20%RH	2.35	56.14	31.72	24.42	11.64
Cement induced RH samples	5%RH+ 2%C	2.56	48.42	27.63	20.79	11.73
	10%RH+ 2%C	2.46	50.15	29.42	20.73	10.83
	15%RH+ 2%C	2.41	51.92	31.39	20.53	10.46
	20%RH+ 2%C	2.38	53.51	34.13	19.38	10.34

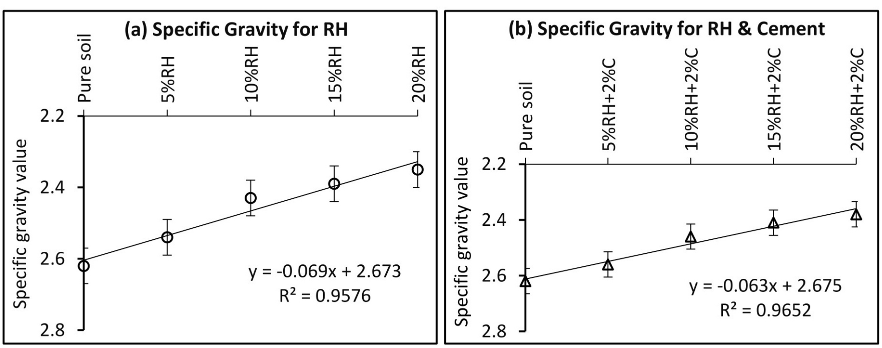

Fig. 3. Variation of specific gravity of the soils with RH mixed and cement induced RH samples.

The gradual increase of liquid limit and plastic limit ultimately made the plasticity index value to decrease throughout the sample range i.e. demonstrated a negative growth (Fig. 6). In RH enriched soil, the plasticity index value varied from 25.54 to 24.42% and it is 20.79 to 19.38% for cement induced RH samples. It is also observed that the terminal decreased is 7.18% and 26.34% for RH mixed and cement induced RH samples respectively. The obtained results of Atterberg limits is consistent with that of SARKAR *et al.* (2012) and BUTT *et al*. (2016) for silty clayey soil and OLOWOFOYEKU *et al.* (2021) and SANI *et al.* (2023) for laterite soil.

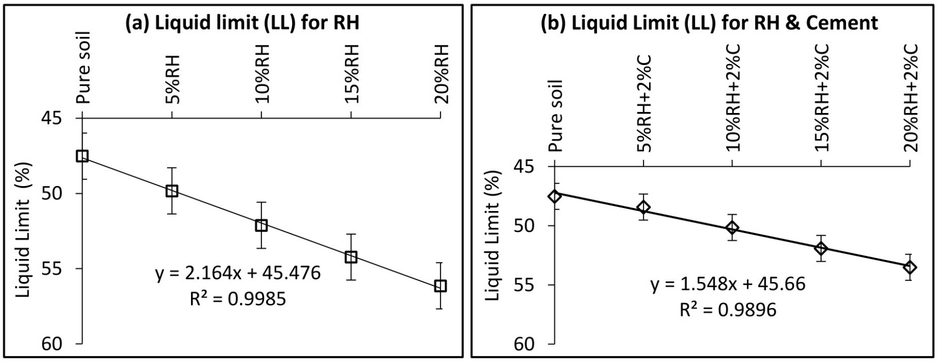

Fig. 4. Variation of Liquid limit of the soils with RH mixed and cement induced RH samples.

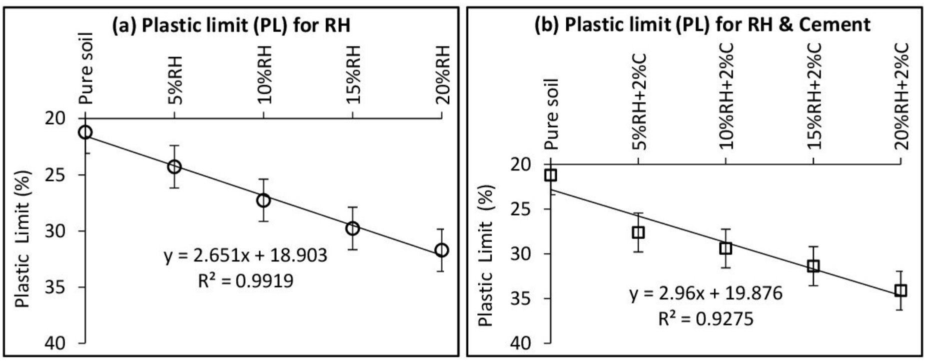

Fig. 5. Variation of Plastic limit of the soils with RH mixed and cement induced RH samples.

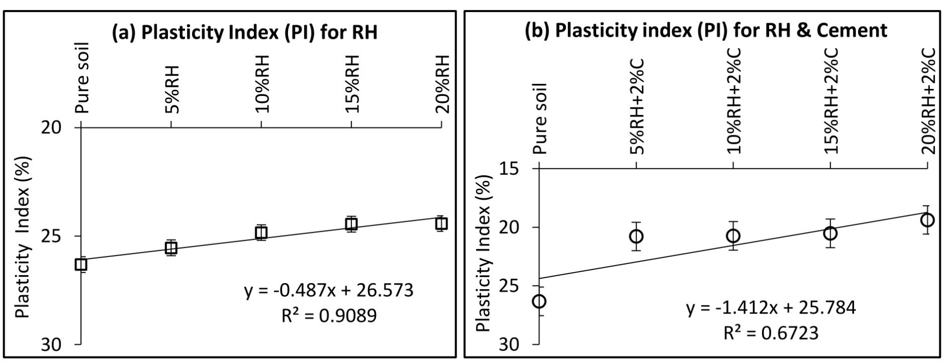

Fig. 6. Variation of Plasticity index of the soils with RH mixed and cement induced RH samples.

The increasing behaviors of liquid and plastic limits might be due to the pozzolanic characteristics of the RH (NIMLYAT & TOK 2013; AGAIBY *et al.* 2022). The hydration process and pozzolanic reaction of additives and soil, created silica content while getting induced with internal and external moisture, which in return increased the liquid limit values. This behavior clarified that the RH induced samples demanded additional amount of water to be transformed into a fluidic state. The reduction of plasticity index, makes the soil behave more like a silty soil rather than clay and signifying a more stabilized soil (BASHA *et al*. 2005; OLOWOFOYEKU *et al.* 2021; AGAIBY *et al*. 2022; KADHIM *et al.* 2022).

The linear shrinkage values ranged from 12.42 to 11.14% and 11.73 to 10.34% for RH mixed and cement induced RH samples respectively and the values decreased with RH content (Fig. 7). However, the value decreased up to 15% RH content then it started to see a growth. In 15% RH mixed samples, linear shrinkage is about 11.14%, which is around 20% reduction over the untreated soil's value of 13.93%. The reason behind the decreasing trend of linear shrinkage might be, with the addition of RH and cement, the plasticity index decreases, making the soil less susceptible to volume changes with variations in moisture, which reduces shrinkage.

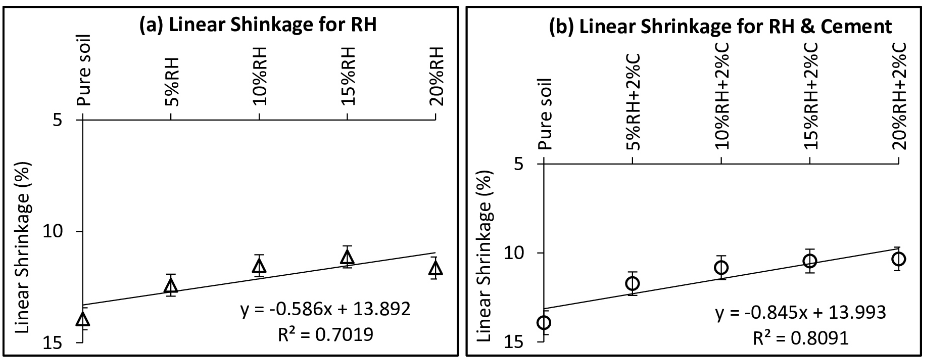

Fig. 7. Variation of linear shrinkage of the soils with RH mixed and cement induced RH samples.

Based on the plasticity chart (after BS 5930, 1981), it is found that, both type of samples is transformed into high plasticity soil as the additives are gradually increased (Fig. 8). The strongest shift toward silt (MH) is found for 15% or more RH mixed samples whereas all the cement induced RH behaved as silt. This curve represented that the soil is initially medium plastic clay, and when supplemented with RH and RH-Cement additives, the samples slowly modified from clay (CI/CH) to silt (MH).

Shear Strength Properties

The shear strength characteristics of nine samples from two different mixture (RH mixed and cement induced RH sample) are measured using the Standard ASTM (1974) methods. The samples under the same normal pressure have been sheared at least three times. A set of normal loads of 10, 20 and 30 kg were applied one after the other in successive tests. The load applied and the strain induced is recorded at frequent intervals to determine a stress–strain curve for each confining stress. The horizontal displacement and shear stress curves show a maximum stress level in each

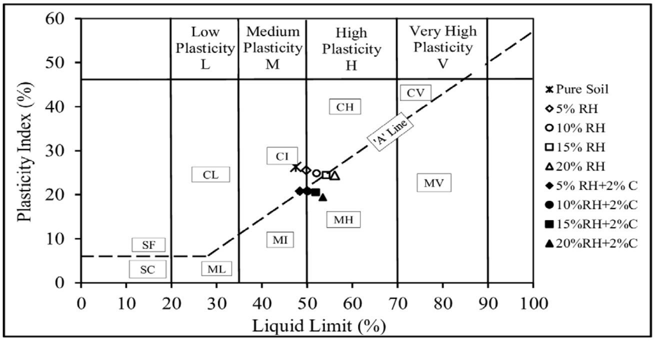

Fig. 8. Plasticity chart showing the clayey the soils, RH mixed and cement induced RH samples (modified after BS 5930, 1981).

case and after reaching the maximum stress level, there is a slight reduction or tends to reach a steady or equilibrium state in shear stress with increasing horizontal displacement (Fig. 9). It is revealed that with increasing RH content, the horizontal displacement was found to be decreasing under all loads and requiring more shear stress to make such displacement. Similar observation also noticed for the cement induced RH samples. The relationship between normal stress and shear stress is

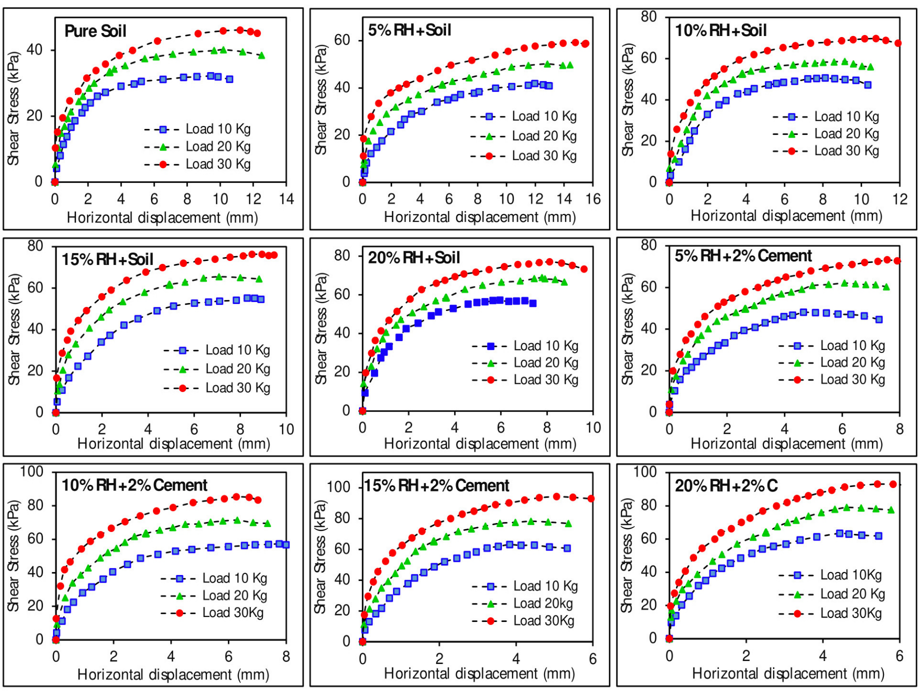

Fig. 9. Relationship between horizontal displacement (mm) vs shear stress (kPa) of pure soil, RH mixed and cement induced RH samples.

shown in Fig. 10. The shear stress increases linearly with increasing normal stress in all the samples. The result of the shear strength parameters (cohesion and angle of internal friction) are given in Table 4 and found that both parameters are increased with the additional inclusion of RH and RH-Cement content (Fig. 11). The cohesion value ranged from 33.03 to 47.88 kPa for RH mixed samples and 35.97 to 48.92 kPa for cement induced RH samples.

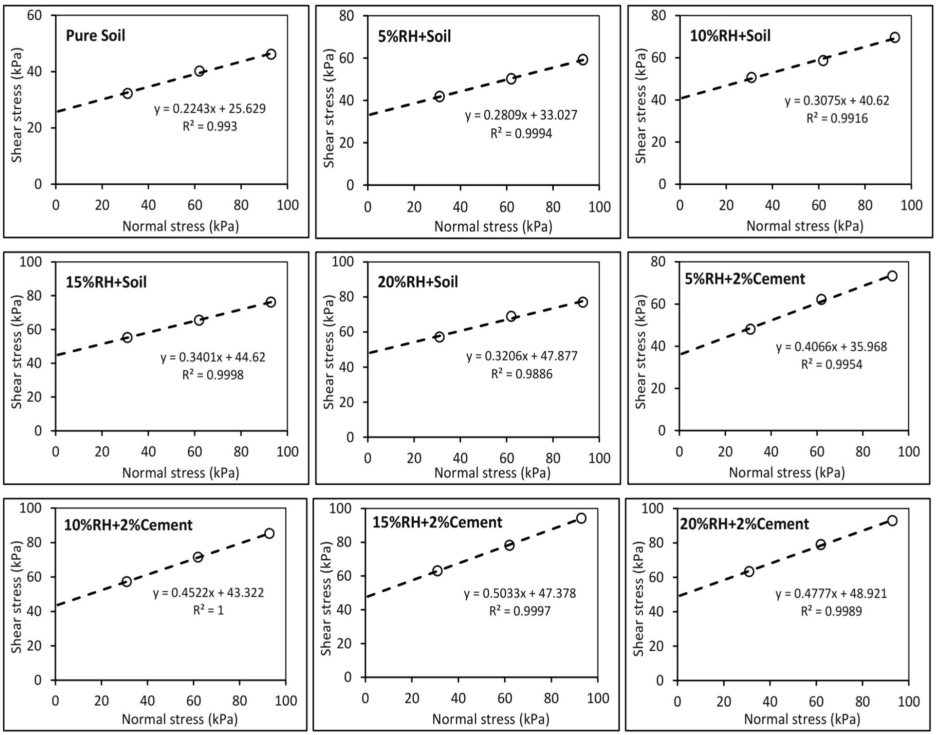

Fig. 10. Relationship between normal stress (kPa) vs shear stress (kPa) of pure soil, RH mixed and cement induced RH samples.

A peak growth of cohesion is almost 87% found for RH mixed samples compared to untreated soil whereas it is around 91% for cement induced RH samples. The angle of internal friction is ranged from 15.72° to 18.82° and 22.17° to 26.76° for RH mixed soil and cement induced RH mixed soils respectively. It is found that the angle of internal friction value, for both the sample group (RH and RH-cement mixed), peaked at 15% rice husk induced mixture, which afterward, started to go down slightly. Capillary suction and strong interparticle contact might contribute to the rise in internal friction angle up to 15% RH. Following this point, lubrication and fabric modifications reduce interparticle contact, causing the internal friction angle to slightly decrease. However, cohesion is still growing due to increased plastic bonding (AGAIBY *et al*. 2022). For RH mixed soil samples, the maximum value of internal friction angle was recorded in the 15% RH mixed sample (18.82°). This indicated a growth of around 48% over the natural soil. At the same time, cement induced 15% RH mixed sample, the angle of internal friction value increased astonishingly 111% over the pure soils which is 26.76°.

From the findings of the soil's shear test result, it can be inferred that the increase of the values throughout the test denotes increase of binding effects as the additives are being introduced (AGAIBY *et al*. 2022). Moreover, high stress capability and angle of internal friction demonstrate the soil's increased compressibility, i.e. stabilization. Furthermore, the increase in cohesion and the angle of shearing resistance might be due to the pozzolanic reaction and the production of fresh calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH), through the process of hydration (STRIPRABU *et al*. 2018; KERAMANTIKERMAN *et al*. 2018). However, it can also be inferred that too much additives, to be specific, more than 15% of rice husk could prove to have a diminishing effect on the stabilization endeavor.

Table 4. Shear strength parameters for pure soil, RH mixed and cement induced RH samples.

Sample	Percentages	Cohesion (kPa)	Angle of Internal Friction (°)
Soil	Pure Soil	25.63	12.67
RH mixed samples	5%RH	33.03	15.72
	10%RH	40.62	17.12
	15%RH	44.62	18.82
	20%RH	47.88	17.81
Cement induced RH samples	5%RH+2%C	35.97	22.17
	10%RH+2%C	43.32	24.38
	15%RH+2%C	47.38	26.76
	20%RH+2%C	48.92	25.58

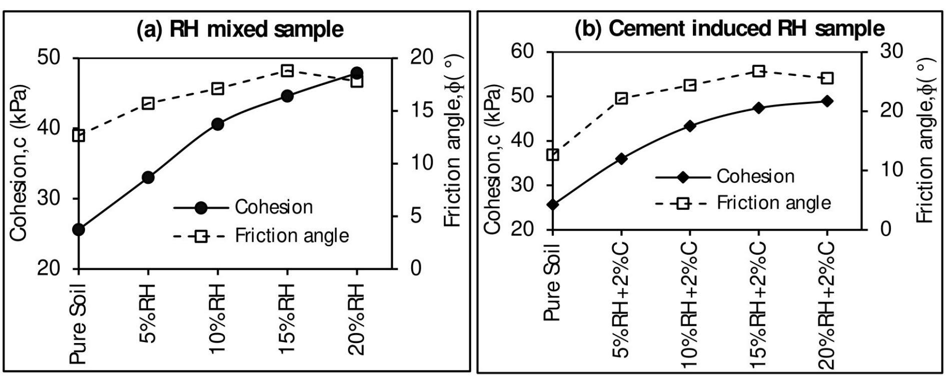

Fig. 11. Variation of Shear strength parameters of soil with RH mixed and cement induced RH samples.

From the obtained results, it may be concluded that employing rice husk (RH) in soft clayey soil has positive effects on soil stabilization and geotechnical properties. The enhancements in shear strength parameters and reduction in plasticity index and shrinkage make these additives highly effective for improving soil performance. However, a detailed study on climatic influences, consolidation test to analyze compressibility and settlement behaviors, SEM test for textural analysis and triaxial test for long term stability is needed for final decision.

Conclusion

To sum it up, this research has found that using rice husk (RH) in the clayey soil has demonstrated a positive effect in stabilizing and improving the geotechnical properties of the soil, with further environmental and cost efficiency. From the test results, it is found that the specific gravity was decreased with the increase of RH content. The liquid-plastic limit value increased in both RH and cement-induced RH mixed soils. A signified decrease of the plasticity index value is observed, which is an indicator of the positive effect of soil stabilization and the altered soil had changed its behavior to that of silty soil. The linear shrinkage value is decreased with increasing RH content which indicates that the soil becomes less prone to shrink in volume when it dries. The cohesion and angle of internal friction both showed an increasing trend throughout sample group. This behavior signifies better stability and shear resistance, an indicator of the improvement of the geotechnical properties. It can also be assumed that, 15% RH and cement induced 15% RH content might be considered as optimum additive quantities, which has demonstrated a balanced soil stabilization effect and provided a soil mixture with enhanced geotechnical properties. Furthermore, for a cost effective and environmentally friendly practice, separate research and governmental institutes should be setup, so that, this kind of research could be implemented for real world testing through proper research and development projects.

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ধানের তুষ এবং সিমেন্ট দ্বারা স্থিতিশীলকৃত কাদামাটির ভূ-প্রকৌশলগত বৈশিষ্ট্য

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সারসংক্ষেপ

ধানের তুষ (Rice Husk), একটি মাটি স্থিতিকরণ (Soil stabilization) উপাদান হিসেবে খরচ-সাশ্রয়ী এবং পরিবেশবান্ধব হতে পারে, কারণ এটি স্থানীয়ভাবে সহজলভ্য এবং এটি নিজে মাটিকে শক্তিশালী করার সক্ষমতা রাখে। এই গবেষণাপত্রে নরম কাদামাটিতে ধানের তুষ ও সিমেন্টের সংমিশ্রণ ব্যবহার করে মাটির স্থিতিকরণের কার্যকারিতা বিশ্লেষণ করা হয়েছে। গবেষণায় কাদামাটিতে বিভিন্ন অনুপাতে ধানের তুষ (৫%, ১০%, ১৫% এবং ২০%) মিশ্রিত করে নমুনা তৈরি করা হয়েছে এবং একইসঙ্গে প্রতিটি নমুনার সাথে একটি নির্দিষ্ট পরিমান অর্থাৎ ২% সিমেন্ট যুক্ত করা হয়েছে। মাটির বৈশিষ্ট্যের উপর ধানের তুষ ও সিমেন্ট-এর প্রভাব বিশ্লেষণের জন্য উক্ত নমুনাগুলোর উপর বিভিন্ন পরীক্ষা (আপেক্ষিক গুরূত্ব, অ্যাটারবার্গ সীমা, রৈখিক সঙ্কোচন ও শেয়ার শক্তি/Shear Strength) করা হয়েছে। ফলাফল বিশ্লেষণে দেখা গেছে, তরল সীমা ও প্লাস্টিক সীমার মান বৃদ্ধি পেয়েছে এবং প্লাস্টিসিটি সূচক কমে গেছে, যার ফলে মাটির শ্রেণিবিন্যাস কাদা থেকে সিল্টে পরিবর্তিত হয়েছে। উপরন্তু, রেখীয় সঙ্কোচনের মান হ্রাস পাওয়া স্থিতিশীলকৃত মাটির সঙ্কোচন প্রতিরোধী আচরণকে নির্দেশ করে।

Direct Shear পরীক্ষা আরও প্রমাণ করেছে যে, স্থিতিশীলকৃত মাটি উচ্চ শেয়ার প্রতিরোধ ক্ষমতা প্রদর্শন করে, কারণ এতে সংযোজন (Cohesion) এবং অভ্যন্তরীণ ঘর্ষণের কোণের (Friction Angle) মান বৃদ্ধি পাওয়া দৃশ্যমান হয়েছে। এছাড়াও, এটি প্রকাশিত হয়েছে যে, কাদামাটির সঙ্গে ১৫% ধানের তুষ (RH) এবং ১৫% RH + ২% সিমেন্ট মিশ্রণ দুটি মাটি স্থিতিশীলকরণের ক্ষেত্রে যথেষ্ট সম্ভাবনাময়, খরচ সাশ্রয়ী ও পরিবেশবান্ধব হতে পারে, কারণ এই দুটি মিশ্রণ মাটির ভূ-প্রকৌশলগত বৈশিষ্ট্যের সবচেয়ে উল্লেখযোগ্য উন্নতি প্রদর্শন করেছে।