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UTILIZATION OF RICE HUSK ASH AS A SUSTAINABLE ADDITIVE FOR SUBBASE STRENGTH ENHANCEMENT

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ABSTRACT: Rice husk is one of the most abundant agricultural wastes in Thailand, and its conversion into rice husk ash (RHA) offers an alternative material for reducing Portland cement usage in soil stabilization. This study investigates the use of RHA as a cementitious replacement to improve subbase strength. RHA was produced through controlled combustion at 600 °C for 3 hours and mashed by ball mill grinding machine. Soil samples were stabilized with 3% binder content by weight and compacted at optimum moisture content by modified compaction effort. Cement was partially replaced with RHA at 10%, 30%, 50%, 70%, and 100% by weight. Unconfined compressive strength (UCS) and capillary rise tests were performed to evaluate strength and water absorption behavior. The results showed that 10% cement replacement with RHA achieved higher compressive strength than conventional cement stabilization at both 28 and 56 days. However, strength decreased progressively with higher RHA content, while complete cement replacement (100% RHA) resulted in weak durability under soaking conditions. Capillary rise tests indicated that the 10% RHA mixture exhibited water absorption characteristics comparable to 3% cement-stabilized soil, whereas 100% RHA behaved similarly to untreated soil. Additionally, mixtures containing 30–70% RHA showed decreasing water absorption with increased curing time. Overall, the findings suggest that RHA can partially replace cement while maintaining satisfactory mechanical and durability performance, contributing to more sustainable soil stabilization.

Keywords: Rice husk ash, Soil stabilization, Unconfined compressive strength, Sustainable construction materials

1. INTRODUCTION

Rice husk is one of the most abundant agricultural wastes in Thailand [1], where approximately 21-26 million tons of rice are produced annually. Most rice husks are burned in the open air unless utilized otherwise. Such wasteful practice provides no benefits and instead cause significant environmental problems. For example, rotting piles of husk release methane, a potent greenhouse gas, while burning husks in the open air produces harmful smoke [2]. This contributes to increased PM2.5 levels, which is a major air pollution issue in northern of Thailand. However, utilizing biomass for power generation presents a viable solution, as Thailand is an agriculture-based society that produces large amounts of agricultural residues, including rice husks. Using rice husks for power generation is a sensible strategy to reduce environmental damage and air pollution caused by open burning. Additionally, rice husk ash is produced as a by-product and can be repurposed for various applications. Due to its high silica content, rice husk ash can be used as an ingredient in industrial materials such as cement, ceramic products, and more [2].

In Thailand, lateritic soil is widely used for building subbase in road construction. This is due to lateritic soil is abundant in Thailand and the price is low. However, it has become a realized problem because of poor-quality lateritic soil which has low compressive strength and durability. Lateritic soil obtained from some areas still does not meet the required standards. Moreover, rain infiltration or the water inundates of the subbase can cause road damage [3,4]. Therefore, soil stabilization techniques are considered suitable due to their economic and sustainable benefits. Soil modification involves the addition of a modifier (such as cement, lime etc.) to alter soil properties, while soil stabilization refers to the treatment of soils to improve their strength and durability [5]. The most commonly used additive for soil stabilization is ordinary Portland cement. However, soil stabilization by using cement alone resulted in high construction costs. Therefore, the use of cement with by-product materials from industry or agriculture can be an alternative for soil stabilization at present. Several successful techniques for utilizing pozzolanic materials, such as fly ash, bottom ash, and FGD gypsum, have been developed. A literature review demonstrated that using ash or pozzolanic materials combined with cement to improve soil strength can reduce cement consumption [3,4]. Therefore, replacing cement with high volumes of pozzolanic materials can improve the cost efficiency of subbase construction. Additionally, Portland cement's production is inherently carbon-intensive, generating substantial CO_2 per ton manufactured. Thus, replacing portions of the Portland cement with secondary cementitious materials in soil stabilization can reduce the overall environmental impact of the stabilization process [5]. This established method confirms that pozzolanic materials can effectively improve soil bearing capacity through stabilization [3,4,6]. However, the engineering properties of subbases stabilized with pozzolanic materials should be evaluated according to the requirements of Thailand's Department of Highways.

In order to reduce the environmental impact of the stabilization process of subbase, this study focused on replacing cement with rice husk ash to stabilize the strength of subbase materials. Literature review illustrated rice husk is properly burned at a temperature below 800 °C, rice husk ash (RHA) with a cellular microstructure and a high percentage of amorphous SiO_2 is produced [1]. The resulting RHA is highly suitable for use as a pozzolanic material to enhance the compressive strength and durability of cement-based materials [7]. RHA can act as a source of excess SiO_2 to chemically reacting with $Ca(OH)_2$ (a byproduct of cement hydration) to form additional calcium silicate hydrate (C-S-H), the primary strength-contributing compound in cement-based materials. This so-called pozzolanic effect is particularly pronounced in RHA with a high amorphous SiO_2 content, as this form of silica is the most chemically reactive with $Ca(OH)_2$ [1]. Additionally, the potential of RHA as soil stabilization materials. The optimal amount of RHA in soil can enhance long-term strength [5]. The increase in the RHA content at specified cement content also improved UCS values with curing age [8]. Therefore, this study focused on utilization of rice husk ash as a sustainable additive for subbase strength enhancement.

2. RESEARCH SIGNIFICANCE

This study promotes sustainable soil stabilization by utilizing rice husk ash (RHA), an abundant agricultural by-product, as a partial replacement for Portland cement in subbase construction. Reducing cement use offers a practical approach to lowering the environmental impact of stabilization works. The influence of 10–100% RHA replacement on soil strength and water absorption was examined. RHA was produced through controlled combustion at 600 °C, and performance was evaluated using unconfined compressive strength and capillary rise tests. The results identify an optimal replacement level that enhances mechanical properties while supporting more environmentally responsible geotechnical practices.

3. MATERIALS AND METHODOLOGY

3.1 Lateritic Soil

The soil samples used in this study is lateritic soil from local areas in Chiang Mai, Thailand. The properties of the soil samples, including a particle size distribution, specific gravity, liquid limit, plastic limit, optimum moisture content and maximum dry density were investigated. The engineering properties of the soils were measured in accordance with the standard set by the Department of Highway (DOH), Thailand, for use as soil-cement subbase material [9].

The specific gravity of the soil samples was determined in accordance with ASTM D854 [10]. To analyze the particle size distribution, wet sieving tests and hydrometer tests were conducted following ASTM D422 [11]. Liquid limit and plastic limit tests were performed on soil samples passing through a 0.425 mm sieve, following ASTM D4318-00 [12]. Additionally, the optimum moisture content and maximum dry density of the soil were determined using modified Proctor compaction tests in accordance with ASTM 1557 [13].

3.2 Rice Husk Ash

The rice husk used in this study was collected from the Lanna Rice Research Center at Chiang Mai University. The rice husk was golden to light brown, with a curved and rigid shape and a rough surface. Its bulk density ranged between 100-150 kg/m^3. In this study, RHA was used as cement replacement material. A commercial type of Portland Cement (Type 1) was used as the base material.

To prepare the rice husk ash (RHA), rice husk was burned in an oven at 600 °C for 3 hours. Color of burning RHA illustrated blackish grey and whitish grey. The whitish grey color shows higher content of silica. However, blackish grey color shows high content of unburnt carbon. Subsequently, the RHA was mashed using a ball mill grinding machine for 90 minutes to achieve a particle size finer than 0.075 mm, as shown in Fig. 1.

Fig.1 Burning rice husk ash and rice husk ash mashed ball mill grinding machine

3.3 Sample Preparation and Testing

3.3.1 Unconfined compressive strength (UCS) testing

The UCS tests were conducted in accordance with ASTM D1633 (Method A) [14] using cylindrical specimens measuring 101.6 mm in diameter and 116.4 mm in height. The soil samples were mixed with a binder at 3% by weight of soil in different ratio, as shown in Table 1. Ordinary Portland cement was partially replaced with RHA at 10%, 30%, 50%, 70%, and 100% by weight. The water added to the mixture was set to the soil's optimum moisture content.

The samples were compacted in five layers, with each layer compacted 25 blows from a 10 lb hammer to achieve modified compaction energy. After compaction, each sample was extruded from the mold and cured in a seal plastic bag to prevent moisture loss during the curing period of 7, 28 and 56 days. Prior to testing, the cured samples were soaked in the water for 2 hours and air-dried for 15 minutes. The samples were then subjected to compression testing to evaluate the strength improvement of the soil. The compressive strength values for each mixture represent the average of three specimens. The results demonstrate the potential of using agricultural wastes materials (RHA) as a partial cement replacement to enhance the strength of subbase materials.

Table 1. Mixture proportion of soil-cement-RHA

Mixture	Cement replacement by RHA (%)	Raw materials (g)		
		Soil	Cement	RHA
C3%	0	2700	81	0
RHA10	10	2700	72.9	8.1
RHA30	30	2700	56.7	24.3
RHA50	50	2700	40.5	40.5
RHA70	70	2700	24.3	56.7
RHA100	100	2700	0	81

Note: The amount of water in the mixture is equal to optimum moisture content of soil.

3.3.2 Capillary Rise Testing

Capillary rise tests were conducted on the stabilized specimens to evaluate water absorption in the improved soil. The tests followed the Australian Standard AS1141.53 [15]. The specimen dimensions were identical to those used in the UCS tests.

The specimens were prepared using the modified compaction method and cured in seal plastic bag for 7, 28, 56 days, following the same procedure as the UCS sample preparation. Prior to testing, the specimens were oven- dried at 60 °C for 72 hours and air-cooled for 2 hours. Subsequently, the samples were partially submerged in a water container, maintaining a 10 mm water height for 72 hours. The capillary rise (increase in water height) was measured as shown in Fig. 2.

Fig. 2 Capillary rise test conducted on specimens

The reported water height for each mixture represents the average of three specimens. Height (h) of water rise from base of specimen was measured using a ruler and was recorded at various times. The capillary rise (CR) as a percentage of the specimen height (H) were determined as follows Eq. (1). The complete testing scheme for this study is presented in Table 2.

$$CR = \frac{h \times 100}{H} \tag{1}$$

Table 2. Testing scheme

Properties	Tests	Moisture	Curing Time (days)
Compressive Strength	Unconfined compressive strength	OMC of soil	7, 28 and 56
Water absorption	Capillary rise test		7, 28 and 56

4. RESULTS AND DISCUSSION

4.1 Engineering Properties of Soil

Soil samples were tested for liquid limit and plastic limit (Atterberg limits test), particle size distribution (sieve analysis and hydrometer tests), and compaction characteristics (modified compaction test) to determine their engineering properties. The test results showed liquid limit, plastic limit, and plastic index values of 20%, 17%, and 3%, respectively. The particle size distribution of the soil samples is presented in Fig. 3.

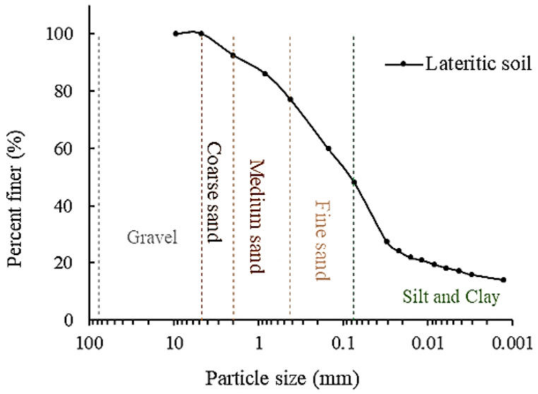


Fig. 3 The particle size distribution of soil sample

The results indicated that 48% of the soil particles were finer than 0.075 mm. Based on these characteristics, the soil was classified as silty sand (SM) according to the Unified Soil Classification System (USCS). All tests were conducted in accordance with the standards specified by the

Department of Highways (DOH), Thailand, for soil-cement subbase materials [9]. The complete test results are summarized in Table 3.

Table 3. The engineering properties of soils

Properties	Lateritic Soils	DOH Standard (Subbase Materials)
Specific gravity, G_s	2.65	Not specified
Liquid Limit, LL (%)	20	≤35
Plastic Limit, PL (%)	17	Not specified
Plastic Index, PI (%)	3	≤11
Passing No. 200 (%)	48	≤40

The results of modified compaction tests are shown in Fig. 4. The compaction curve represents the relationship between dry density and moisture contents of the soil samples in this study. The results demonstrated maximum dry density and optimum moisture content (OMC) of soil samples was 2,035 kg/m^3 and 10.2%, respectively. Consequently, the optimum moisture content of 10.2% was used for sample preparation in both unconfined compressive strength tests and capillary rise tests.

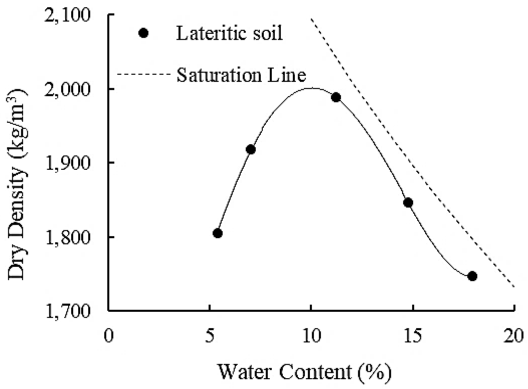


Fig. 4 Compaction test results of soil sample

4.2 Unconfined Compressive Strength of Stabilized Soil

The UCS test results for stabilized soil are summarized in Table 4. The results illustrated that untreated soil and soil samples containing 100% RHA disintegrated after being soaked in water for 2 hours prior to the compression test as shown in Fig. 5. This behavior reflects the absence of cementitious hydration products, which are essential for binding soil particles and maintaining structural integrity under wet conditions. Consequently, specimens without cement exhibited poor durability and were unable to withstand moisture-induced softening. Therefore, the unconfined compressive strengths of the untreated soil and the soil samples containing 100% RHA presented in Table 4 were obtained from unsoaked specimens, as these samples were unable to maintain structural integrity under soaking conditions.

Table 4. Results of unconfined compressive strength tests

Specimen symbol	Cement replacement by RHA (%)	UCS (kPa)			
		0 day	7 days	28 days	56 days
Soil*	-	427	-	-	-
C3%	0	-	1,484	1,698	1,874
RHA10	10		1,398	2,078	2,238
RHA30	30		1,097	1,276	1,621
RHA50	50		1,033	1,212	1,446
RHA70	70		613	736	882
RHA100*	100		624	1112	1694

Note: Unconfined compressive strengths of the untreated soil and the soil samples containing 100% RHA* were obtained from unsoaked specimens.*

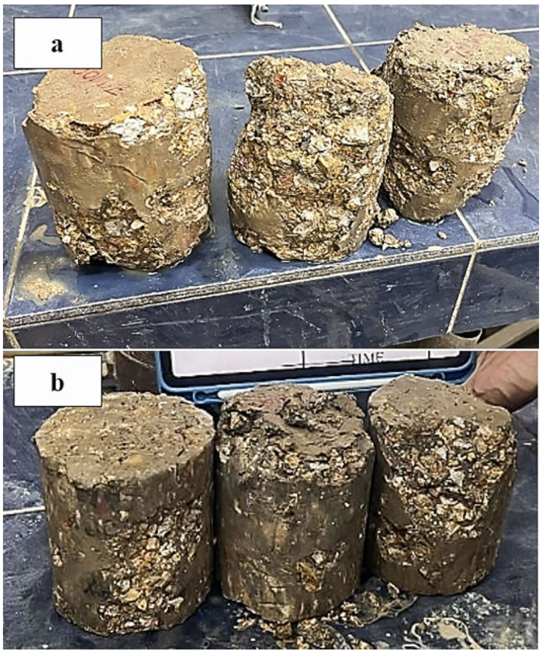


Fig. 5 Untreated soil (a) and soil samples containing 100% RHA (b) disintegrated after being soaked in water for 2 hours

The unconfined compressive strength of untreated soil was 427 kPa. Unconfined compressive strength of the samples containing 10-70% RHA illustrated in Fig. 6. The results demonstrated the soil strength increase with binder addition. Specimens with 10% RHA replacement demonstrated the highest strength at 28 days and 56 days curing periods, while 3% cement mixtures showed the highest strength at 7 days. According to DOH standards [9], the minimum required 7 days UCS for subbase applications is 689 kPa. The tested mixtures (C3%, RHA10, RHA30, and RHA50) all exceeded this requirement, with C3%

showing particular effectiveness for early strength development.

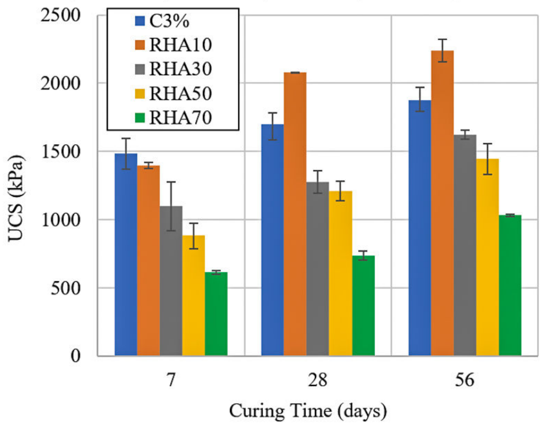


Fig. 6 Unconfined compressive strength of stabilized soil

The effect of RHA as a partial cement replacement on the strength development of the stabilized soil was considered, as shown in Fig. 7. The results demonstrated that the strength of the samples tended to decrease as the proportion of RHA in the mixture increased after 7 days of curing. This is due to the early strength of the soil mixed with cement results from the formation of primary cementitious compounds, such as C-S-H, which are generated by the hydration reaction between cement and water [16].

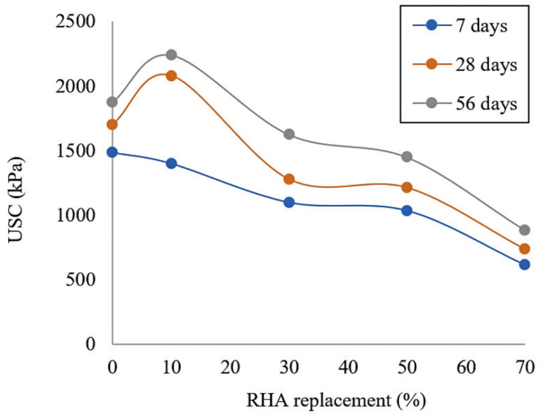


Fig. 7 Effect of RHA as a partial cement replacement on unconfined compressive strength

Additionally, Fig. 7 shows that replacing cement with 10% RHA can enhance long-term strength more effectively than using cement alone, as observed after 28, and 56 days of curing. The strength of the RHA10 mixture was approximately 19-22% higher than that of the C3% mixture. When RHA is incorporated into the mix, a pozzolanic reaction occurs, producing calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH), which results in increased soil strength [17]. However, when RHA was used to replace more than 10% of cement, the strength tended to decrease as the RHA proportion increased.

Fig. 8 presents the unconfined compressive strength of soil samples containing 100% RHA. The results show that strength increased with longer curing periods. The strengths at 7, 28, and 56 days were 624 kPa, 1,112 kPa, and 1,694 kPa, respectively. The strengths at 7, 28, and 56 days were higher than that of the untreated soil by approximately 197 kPa, 685 kPa, and 1,267 kPa, respectively. These results indicate that RHA alone can contribute to strength development in stabilized soil. However, specimens without cement still exhibited poor durability. These results suggest that RHA alone can promote strength development through pozzolanic reactions, although the absence of cementitious hydration products resulted in poor durability, particularly under wet conditions.

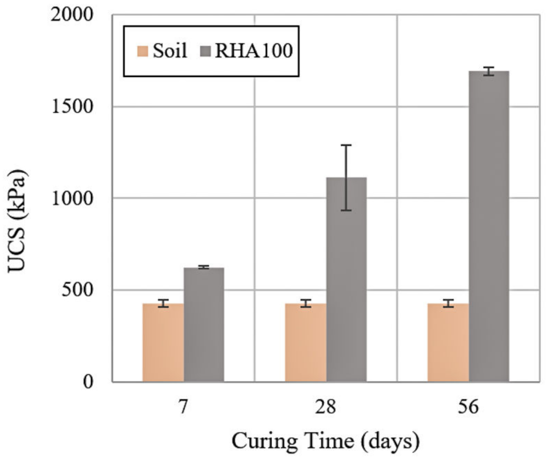
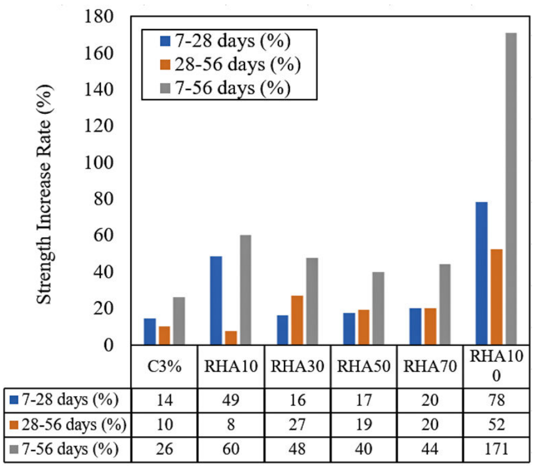


Fig. 8 Unconfined compressive strength of RHA100

Fig. 9 shows the strength increase rate of all the samples. The results demonstrated that RHA10 was the most effective in developing strength between 7 and 28 days, with an increase of approximately 49%. The strength increase rate of RHA10 was about 35% higher than that of C3%. Thus, the results indicate that RHA is effective in enhancing the strength of stabilized soil after 7 days.

When considering the strength increase rate between 28 and 56 days, the results showed that replacing cement with 30% RHA (RHA30) was the most effective, achieving a strength increase of approximately 27%. Moreover, cement replacement with 30-70% RHA was more effective in developing long-term strength compared to RHA10. This suggests that RHA in the mixture triggers a pozzolanic reaction, leading to an increased long-term strength gain.

Overall, replacing cement with 10% RHA (RHA10) was the most effective for strength development, as evidenced by 60% strength increase rate observed over 7-56 days. In contrast, C3% showed only a 26% increase. Additionally, RHA30, RHA50, and RHA70 exhibited higher strength increase rates than C3%, further confirming the effectiveness of RHA in improving the long-term strength of stabilized soil.



	C3%	RHA10	RHA30	RHA50	RHA70	RHA100
■ 7-28 days (%)	14	49	16	17	20	78
■ 28-56 days (%)	10	8	27	19	20	52
■ 7-56 days (%)	26	60	48	40	44	171

Fig. 9 Strength increase rate of stabilized soil (Strength of RHA100 obtained from unsoaked specimens)

Fig. 9 presents the strength increase rate of the RHA100 mixture based on unsoaked specimens. The samples were sealed in plastic bags during curing at 7, 28, and 56 days to prevent moisture loss and were not soaked prior to testing, as the RHA100 specimens disintegrated when exposed to water. The results show that the strength increased by approximately 78% 52%, and 171% at 7–28 days, 28-56 days and 7–56 days, respectively. This indicates that RHA alone can contribute to long-term strength development, likely due to delayed pozzolanic reactions between amorphous silica in RHA and available calcium in the soil. However, in the absence of cementitious hydration products, the binding structure remains highly susceptible to moisture, resulting in poor durability under wet conditions. These findings confirm that although RHA can improve long-term strength, it cannot fully replace cement in applications where water exposure is expected.

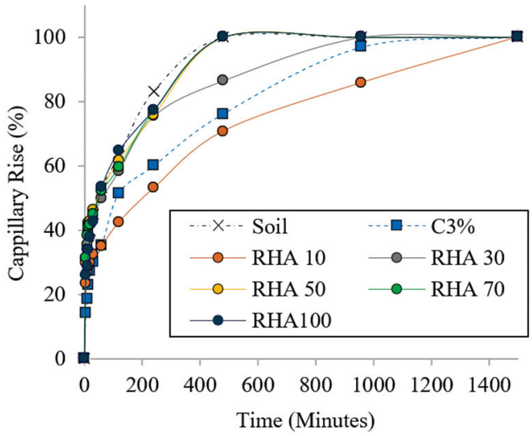
This continued strength development suggests that RHA can promote pozzolanic reactions over extended curing periods. From a pavement engineering perspective, RHA100 may be applicable only in dry subbase conditions where water infiltration is limited, or when combined with other stabilizers that enhance moisture durability. Therefore, while RHA alone provides measurable strength benefits, it cannot serve as a full cement replacement for highway subbase applications exposed to seasonal wetting.

4.3 Capillary Rise of Stabilized Soil

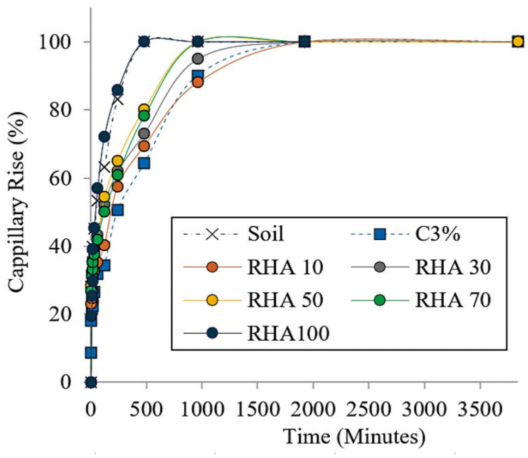
Fig. 10 shows the capillary rise of the specimens after 7, 28, and 56 days of curing, presented as the percentage of capillary rise versus time. After 7 days of curing, the non-stabilized soil, RHA50, RHA70, and RHA100 exhibited similar behavior, all reaching 100% capillary rise at 480 minutes. In contrast, RHA10 and RHA30 yielded lower capillary rise values at the same time, at 71% and 86%, respectively. In addition, RHA10 demonstrated a lower capillary rise than C3% by approximately 5–10% within the first 60 minutes of submersion, suggesting that a small amount of RHA can reduce capillary water absorption more effectively than cement alone.

Fig. 10(b) presents the capillary rise after 28 days of curing. The non-stabilized soil and RHA100 again showed similar behavior, both reaching 100% capillary rise at 480 minutes, confirming a lack of moisture resistance at 100% replacement. However, RHA50 and RHA70 showed delayed saturation, reaching 100% capillary rise at 960 minutes, while RHA10 and RHA30 reached only 88% and 95%, respectively, at the same time. The capillary rise of RHA10, RHA30, and C3% eventually reached 100% at 1,920 minutes.

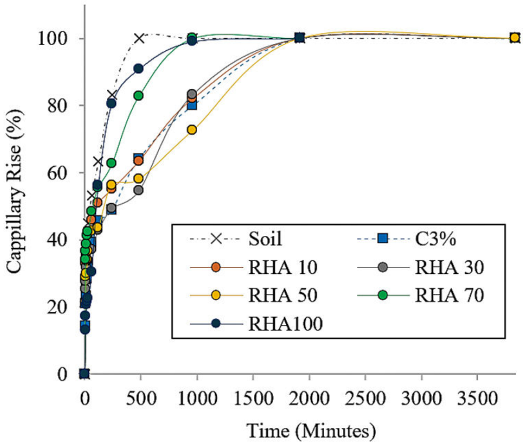
Fig. 10(c) presents the capillary rise at 56 days of curing. The RHA70 and RHA100 mixtures reached 100% capillary rise at 960 minutes. In contrast, the RHA10, RHA30, and RHA50 mixtures exhibited lower capillary rise percentages at the same time, at 82%, 83%, and 73%, respectively. The capillary rise of RHA10, RHA30, RHA50, and C3% eventually reached 100% at 1,920 minutes.



(a) Curing time at 7 days



(b) Curing time at 28 days



(c) Curing time at 56 days

Fig. 10 Capillary rise percentage versus time of stabilized soil after 7, 28, and 56 days of curing

The reduction in capillary rise for RHA10 and RHA30 indicates that partial RHA replacement can improve moisture resistance by reducing the rate of water uptake. Increased curing time further enhances this behavior due to secondary pozzolanic reactions that refine pore structure and slow water transport. However, mixtures containing more than 50% RHA, particularly RHA100, lack sufficient cementitious binding and remain vulnerable to rapid water absorption, indicating that high replacement levels are unsuitable for subbase layers exposed to groundwater or seasonal flooding.

These results suggest that mixtures with higher RHA contents tend to allow faster upward water migration, which is consistent with their more open pore structure and limited cementitious bonding. Reduced capillary rise is desirable for road subbase applications, as upward moisture movement can soften pavement layers and diminish long-term performance. Therefore, mixtures containing small to moderate RHA replacement (e.g., RHA10 or RHA30) appear more suitable for subbase stabilization under conditions where moisture infiltration is expected. In contrast, very high RHA replacement (RHA70–RHA100) may require additional stabilizing agents or surface protection if used in environments subjected to frequent wetting.

5. CONCLUSION

Based on the investigation into the utilization of rice husk ash as a sustainable additive for subbase strength enhancement, the key finding of this study are summarized as follows:

1. Soil mixed with 3% cement or soil mixed with RHA replacing 10-50% of cement achieved strength values exceeding the Department of Highway (Thailand) requirement of 689 kPa after 7 days of curing.
2. Replacing 10% of cement with RHA enhanced soil strength more than using cement alone at 28, and 56 days. Specially, 10% RHA replacement increased strength by approximately 19-22% compared to soil stabilized with 3% ordinary Portland cement (OPC).
3. RHA demonstrated long-term strength development in stabilized soil. A 10% RHA replacement was the most effective for strength gain between 7-28 days, showing 35% higher strength increase rate than cement alone. However, higher RHA replacements (30-70%) resulted in greater strength development at 28-56 days. Thus, RHA can promote pozzolanic reactions over extended curing periods.
4. Replacing 100% of cement with RHA can applicable only in dry subbase conditions where water infiltration is limited, or when combined with other stabilizers that enhance moisture durability. Therefore, RHA alone provides measurable strength benefits, it cannot serve as a full cement replacement for highway subbase applications exposed to seasonal wetting.
5. Replacing of cement with RHA reduces water absorption in stabilized soil. Reduced capillary rise is desirable for road subbase applications, as upward moisture movement can soften pavement layers and diminish long-term performance.
6. The use of RHA increases subbase soil strength while decreasing cement usage, consequently reducing the environmental impact associated with soil stabilization.

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