

Stabilization of Alluvial Soils with Cement and Cement–Rice Husk Ash Blend for Low-Volume Road Construction in Bangladesh

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Rice husk, produced by milling rice, has been used to a large extent as boiler fuel in rice mills in Bangladesh. The rice husk ash (RHA) produced has created a disposal problem. A study was conducted to examine the characteristics of alluvial silty soils stabilized with ordinary portland cement and portland cement–RHA blend and to assess their applicability for low-volume road construction in Bangladesh. Stabilized samples were prepared at maximum dry density and optimum moisture content determined by AASHTO T99. The samples were cured and tested for durability, volume and moisture change characteristics, unconfined compressive strength, and plasticity. Cement-treated alluvial soils satisfy the durability criteria recommended by the Portland Cement Association (PCA) at about 9 percent cement content. At this cement content, however, they do not attain the specified minimum unconfined compressive strength. Silty soils stabilized with only 2 percent cement content show considerable gain in unconfined compressive strength over untreated soil. RHA can be blended with cement to stabilize silty soils. A partial replacement of cement by as much as 25 percent of ash by weight is possible without impairing durability or appreciably decreasing strength compared with samples containing cement only. RHA addition results in an increase in volume on wetting of the soil–cement–RHA mixture and decreases the maximum dry density of the soil. Higher ash content results in an increase in the plasticity of the cement–RHA-stabilized soil.

Bangladesh has a main highway network of 6,770 mi, including approximately 2,900 mi of unpaved roads. Because of low topography, roads are built on fill soils from nearby borrow pits. Most unpaved roads are minimally compacted earth roads built on fill soil that serve the rural communities and provide connections with the regional growth centers. Traffic volumes on these roads are very low, consisting mostly of animal-drawn wagons carrying farm produce and occasional motorized vehicles. Annual maintenance practices include dumping loose soil from nearby borrow pits over the road formation in winter and rendering nominal compaction, usually by manual methods. Due to limited resources, state-of-the-art compaction equipment and quality control methods are not applied for

this type of secondary road construction. These roads subsequently are exposed to rain and monsoon floods. These environmental factors, together with inadequate compaction, seriously impair their durability. Most of the roads become impassable in the rainy season. For paved-road construction, greater pavement thickness is required because of the weak subgrade material. Cement stabilization of local soils has been suggested as an alternative way to improve the characteristics of borrow and in-place soils in earth and paved-road construction (1). The cost savings achieved by stabilized earth roads is well established (2).

In a developing country such as Bangladesh, it is extremely difficult to mobilize resources for road construction. Use of local materials is an important prerequisite for proper and economical road construction. Rice husk ash (RHA) is an agricultural waste produced by the rice boilers. In Bangladesh, annual rice production is around 13.5 million tons, resulting in a considerable amount of ash. RHA has potential as a construction material similar to pulverized fuel ash (PFA) produced in pulverized coal-fired electricity-generating plants.

Cement has long been used in soil stabilization. The use of RHA with lime as a stabilizer has been investigated and found successful (3,4). A limited study in Bangladesh (5) has demonstrated that a portland cement–RHA blend in a 1:1 ratio can be used in masonry work satisfying ASTM specification C91 for masonry cement. Ahmed (6) investigated the geotechnical properties of some Bangladeshi silty soils stabilized with cement and lime. However, the quality of lime in Bangladesh is poor and shows a high variability in properties. Also, no previous work has been done on cement–RHA stabilization of soils. An experimental analysis was required to establish the applicability of cement–RHA stabilization for alluvial silty soils in Bangladesh.

SOILS OF BANGLADESH

The surfacial geology of Bangladesh can be split into three formations: (a) tertiary and pleistocene hill formations, (b) uplifted alluvium terraces, and (c) recent floodplain and piedmont alluvium. Of these, recent floodplain and piedmont alluvium occupies nearly 70 percent of the land area. The floodplain deposits are of recent origin, and soils alternate in

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repeated layers of clays, silt, and sands. Rivers in this formation are flat in gradient and deposit fine soil particles, predominantly silt and clay, every year. Major portions of the deposits are inundated by seasonal flooding. As a result, the subsoil becomes soft and has low density and shear strength. The high groundwater table at other times of the year also contributes to the low density and bearing capacity of the subsoil. The strength of these soils must be improved for road construction.

MATERIAL CHARACTERISTICS

Silts are abundant in the floodplain alluvium. The soils in this formation do not vary widely in their index properties and textural compositions (1). Two representative silty soil samples from this formation were selected for this study, one with no plasticity and the other with little plasticity. Table 1 presents the properties of untreated soils, and Figure 1 shows the grain size distribution of these soil samples. Both soils are classified as AASHTO A4. Type I portland cement meeting ASTM standards was used as the primary stabilizing agent.

RHA was produced by burning rice husk under controlled temperatures of 500°C to 525°C in the laboratory. The burning was discontinued after visual identification of white ash, which signified low carbon content. The ash was ground in a ball mill and sieved to pass through a No. 200 sieve. The chemical

composition of the RHA was then analyzed, and the results are presented in Table 2.

MECHANISM OF SOIL-CEMENT STABILIZATION

Addition of cement has a twofold effect on fine-grained silts and clay: (a) acceleration of flocculation and (b) promotion of chemical bonding. Because of flocculation, the clay particles are electrically attracted and aggregated with each other. This attraction results in an increase in the effective size of the clay aggregation, converting it into the mechanical equivalent of the silt (7,8). The chemical bond aggregates the particles in a cellular structure. Because flocculation binds the clay particles in a matrix form, the cement reduces plasticity and increases shear strength. The chemical surface effect of the cement reduces the water affinity of the clay and subsequently the water-retention capacity of the clay. This action results in the enclosure of the larger unstabilized grain aggregates, which, cannot expand and thus gain improved durability.

The cement-clay interaction is significantly affected by the interaction of lime, produced during hydration of cement and the clay minerals. The interaction can be classified into two groups: (a) rapid rate (ion exchange and flocculation) and (b) slow processes (carbonation, pozzolanic reaction, and the production of new substances). The products of rapid rate processes harden into high-strength additives, whereas the slow

TABLE 1 PROPERTIES OF UNTREATED SOIL

Soil Property	Soil - A	Soil - B
Textural Composition:		
(MIT Classification)		
Sand, % (2 mm - .06 mm)	14	6.5
Silt, % (.06mm - .002mm)	86	89.5
Clay, % (<.002mm)	0	4.0
Percent passing # 200 sieve	95	98.0
Materials smaller than 0.05 mm, (%)	81	84.0
Atterberg limits and indices:		
i) Liquid limit	-	33.0
ii) Plastic limit	-	27.5
iii) Plasticity Index	-	5.5
Natural moisture content	26	23.0
Specific gravity	2.63	2.68
Engineering Properties:		
Optimum moisture content, % (AASHTO T99)	15	18
Maximum dry density, pcf	98.5	104.6
Unconfined Compressive Strength, psi	9.67	11.23
Chemical Properties:		
pH	7.2	6.6
Organic matter content, %	0.71	0.62
Classification:		
AASHTO	A-4	A-4(0)
Unified/ASTM	ML	ML
General Rating as Subgrade:		
AASHTO	Fair to Poor	Fair to Poor
Unified/ASTM	Not Suitable	Not Suitable

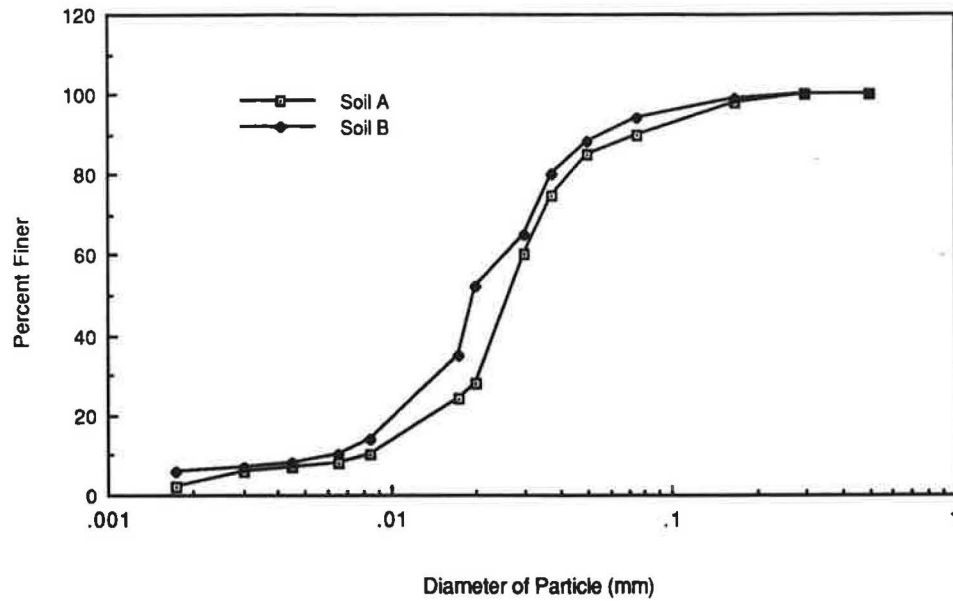


FIGURE 1 Grain size distribution curves of tested soils.

processes increase the strength and durability of the soil-cement mix by producing an additional cementing substance to further enhance the bond strength between the particles (2).

ROLE OF RHA IN STABILIZATION

Chemical analysis of RHA indicates the presence of silica as a primary constituent. The silica may be present in the ash in amorphous form. The combination of amorphous silica in RHA with calcium hydroxide, either as slaked lime or as a byproduct of hydrating cement, results in a cementing agent such as pozzolanic cement (9). The fine ash also acts as a source of reinforcement in the set cement (10).

TEST PROGRAM

Soil samples were selected for research on the basis of index properties, pH, and organic matter content recommendations of the Indian Road Congress (11) for soil-cement stabilization. Samples were compacted to find optimum moisture content and maximum dry density by AASHTO T99. The samples

were tested for unconfined compression at the maximum dry density. Next, the soils were stabilized with cement using cement contents of 2, 4, 6, 8, and 10 percent by weight of air-dried soil and subjected to a wetting and drying test. Of the cement contents used, the minimum cement content required to satisfy the soil-cement loss criteria specified by the Portland Cement Association (PCA) (12) was 10 percent for both soils. The stabilized samples with cement contents of 2, 8, and 10 percent were tested for unconfined compressive strength. The 2 percent cement content was selected to assess the strength characteristics of cement-modified alluvial silty soils, whereas the other two cement contents were selected on the basis of recommendations by Catton (13) for AASHTO A4 soils.

The soils were later stabilized with admixtures of portland cement and RHA blend at optimum moisture content, keeping the total amount of admixture equal to 10 percent. Cement was replaced in the total admixture by RHA in proportions, cement to RHA, of 3:1, 2:1, and 1:1 by weight. These cement-RHA-stabilized samples were tested to evaluate plasticity characteristics, durability, and unconfined compressive strength by the Atterberg limits test, wetting and drying test, and test for unconfined compression, respectively. Details of the tests

TABLE 2 CHEMICAL COMPOSITION OF RHA

Constituent Present	Percent by Weight
SiO ₂	91.08
Al ₂ O ₃	0.56
Fe ₂ O ₃	0.60
CaO	1.23
MgO	1.30
Loss on ignition	5.23

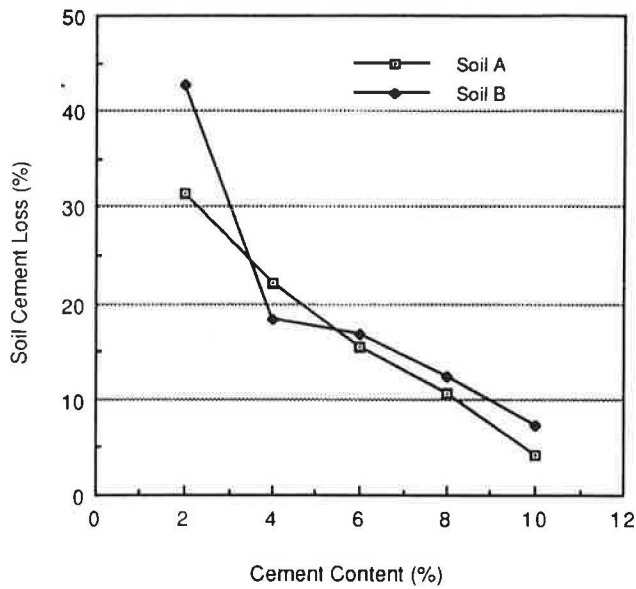


FIGURE 2 Effect of admixture content on soil-cement loss of soils in wet-dry test.

along with the standard methods followed can be found elsewhere (14).

TEST RESULTS, ANALYSIS, AND DISCUSSIONS

Minimum Cement Content

The wet-dry tests were conducted on cement and cement-RHA-stabilized soils to assess the durability, moisture, and volume change of the stabilized soils. The samples were subjected to 12 cycles of wetting and drying. Tests were done on two sets of samples, one for finding volume and moisture change and one for determining soil-cement loss.

The test results were used to determine the minimum cement content required for soil-cement mixtures to satisfy the PCA soil-cement loss criteria. Figure 2 shows the relationships between soil-cement loss and cement content for Soils A and B. Higher cement contents reduce the soil-cement loss in the wet-dry test. Cement contents of 8.1 and 9.0 percent for Soils A and B, respectively, meet the PCA criteria of a maximum of 10 percent soil-cement loss for AASHTO A4 soil. These cement contents also satisfy the PCA recommendation of 7 to 12 percent cement for stabilization of AASHTO A4 soils.

Figure 3 shows the relationships between the soil-cement loss in the wet-dry test and the amount of RHA. As shown, the soil-cement loss increases with increasing ash replacement of cement. The amount of cement that can be replaced by ash is 25 percent for Soil A and 31 percent for Soil B to meet the PCA criteria for soil-cement loss in the wet-dry test. Soil B has a 4 percent clay content, which can be used to explain the higher ash replacement of cement for Soil B than Soil A corresponding to a 10 percent soil-cement loss.

Moisture Change

Maximum moisture content is the highest amount of water in the stabilized sample during wet cycles of the wet-dry test.

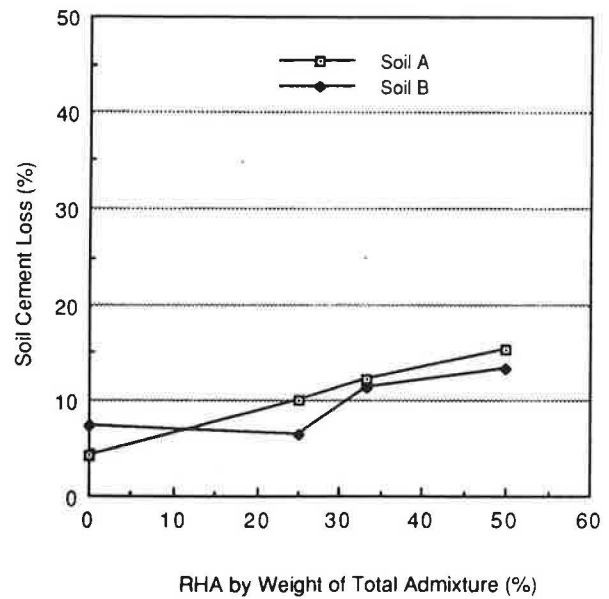


FIGURE 3 Effect of replacement of cement by RHA in the total admixture on soil-cement loss of soils.

Figure 4 shows the maximum moisture contents for Soils A and B versus cement contents. The maximum moisture content occurs at 10 percent cement content. Figure 5 shows the maximum moisture contents in Soils A and B when stabilized with RHA and cement. From this figure, it is evident that RHA addition has little effect on maximum moisture content.

Volume Change

The relationships between volume change and percent of cement content for Soils A and B are shown in Figure 6. Increasing cement content produces shrinkage in both soils due to shrinkage during the cement hydration. Addition of RHA decreases shrinkage, as shown in Figure 7.

Unconfined Compressive Strength

The relationship among unconfined compressive strength, cement content, and curing period are shown in Figures 8 and

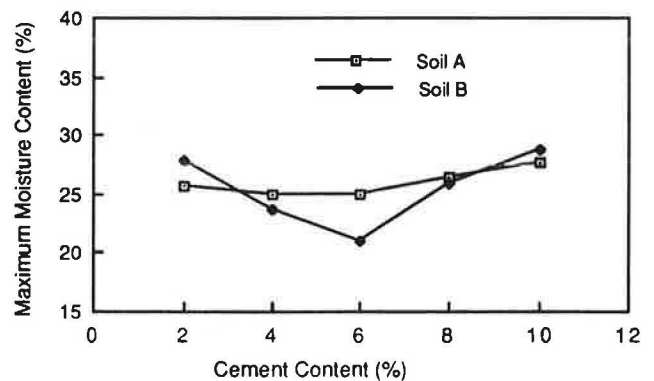


FIGURE 4 Maximum moisture content in cement-stabilized soils during wet cycles of wet-dry test.

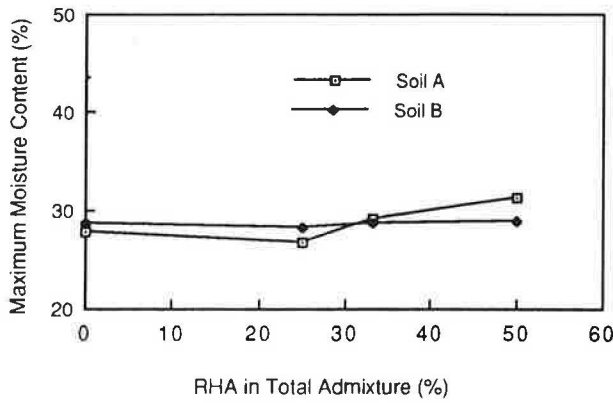


FIGURE 5 Maximum moisture content in cement-RHA-stabilized soils during wet cycles of wet-dry test.

9 for Soils A and B, respectively. The data points represent the average of two test results, and the coefficient of variation is less than 10 percent. Increasing cement content and curing period increases the strength of the treated silty soils. Table 3 and Figures 10 and 11, respectively, show the ratio of unconfined compressive strength of cement-stabilized (UC) Soil A and Soil B to that of untreated soils (UC) at 7, 14, and 28 days.

For Soil A, the addition of 2 percent cement produces a strength ratio of 3.42 for a 7-day curing period and 11.14 for 28 days. For Soil B, corresponding values are 5.16 and 11.43. For 10 percent cement content, the corresponding strength ratios are 11.48 for 7 days and 18.65 for 28 days for Soil A; for Soil B, these values are 11.75 and 17.13, respectively. Clearly, increasing cement content five times does not produce a corresponding gain in strength for these soils. However, for both the soils, an appreciable increase in strength can be achieved by mixing a small amount of cement (i.e., 2 percent) and allowing curing.

At 10 percent cement content, the 7-day unconfined compressive strengths are 110.96 and 131.96 pounds per square inch (psi) for Soil A and Soil B, respectively. PCA (12) rec-

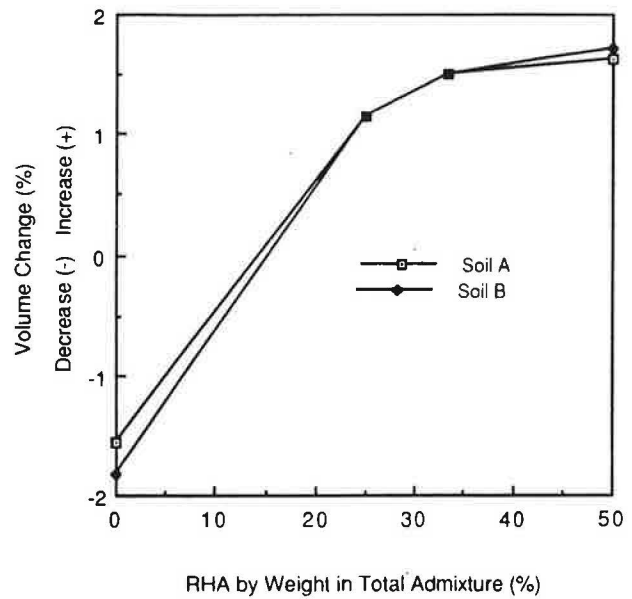


FIGURE 7 Volume change of cement-treated soils on addition of RHA in wet-dry test.

ommends a minimum 7-day unconfined compressive strength of 250 psi for soil-cement mixtures not containing material on a No. 4 sieve, 50 percent of which are smaller than 0.05 mm. The silty soils in the present study failed to achieve the specified strength at 10 percent content. However, both the soils have more than 50 percent materials smaller than 0.05 mm. Thus, the PCA recommendation regarding strength is of questionable validity when applied to typical silty soils in Bangladesh.

In the United States, the desired cement content is normally selected for durability. The implied assumption is that strength needs will automatically be met (15). This is not true for the silty soils evaluated in this research. The results in this study confirm the finding by Ahmed (6), who showed that stabilization of Bangladeshi silty soil of Type A4 requires 14 percent

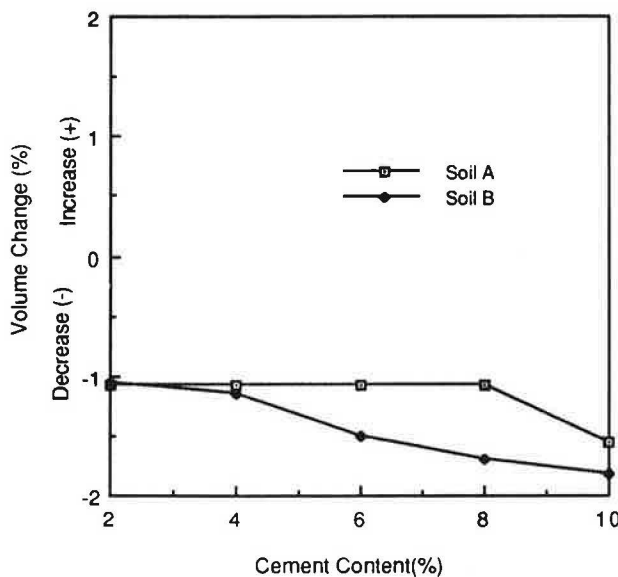


FIGURE 6 Volume change of cement-treated soils in wet-dry test.

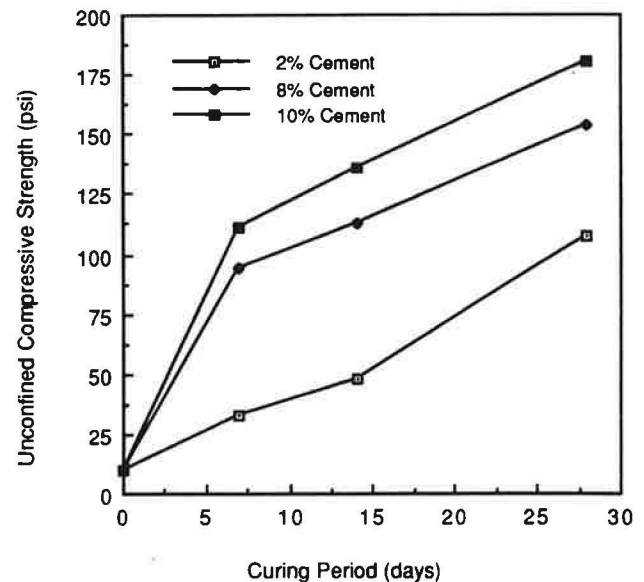


FIGURE 8 Effect of admixture content and curing period on compressive strength of Soil A.

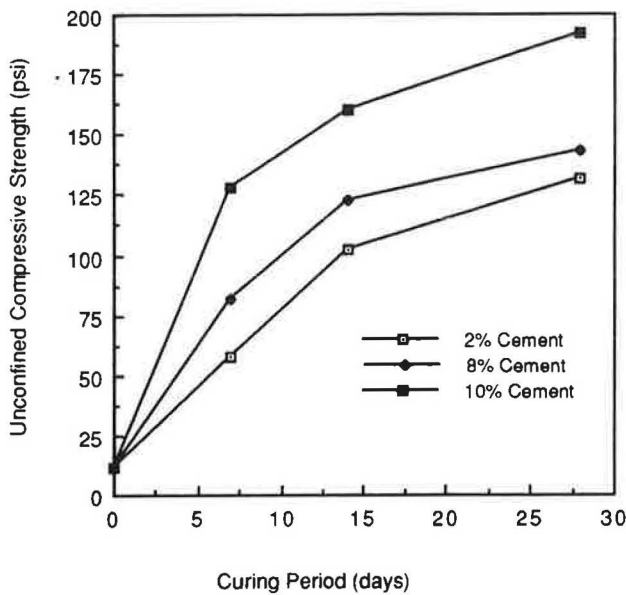


FIGURE 9 Effect of admixture content and curing period on compressive strength of Soil B.

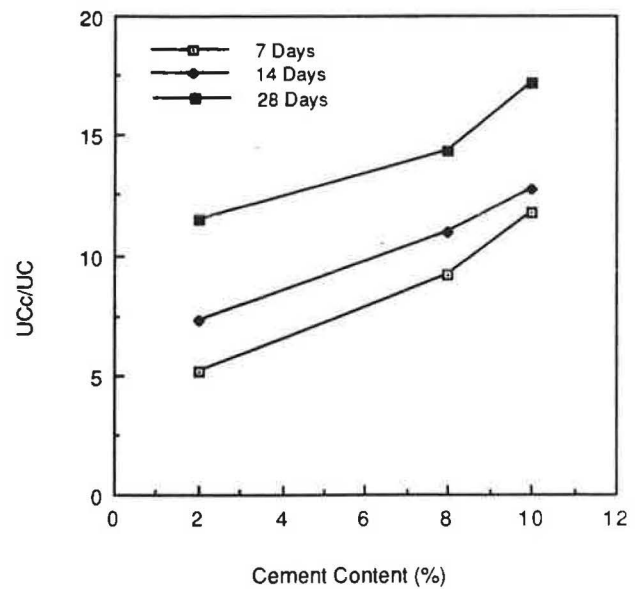


FIGURE 10 Strength ratio of cement-treated Soil A to untreated soil.

cement content and that Type A4 (10) requires a much higher cement content to meet the PCA strength criteria.

Effect of RHA on Strength

The effect of replacement of cement by RHA on unconfined compressive strength of Soils A and B is shown in Figures 12 and 13, respectively. Increasing ash content decreases strength relative only to cement-stabilized soil.

Table 4 and Figures 14 and 15 show the ratio of unconfined compression (UC_{RHA-c}) of stabilized Soils A and B using RHA and cement-blended admixture to that of cement-admixed soil.

For Soil A, 25 percent by weight of cement can be replaced by RHA with only a 5.5 percent decrease in 7-day unconfined compressive strength and with no change in 14-day unconfined compressive strength. The test results show that change is pronounced for ash contents higher than 25 percent and curing periods longer than 14 days.

For Soil B, lower 7-day compressive strength is obtained on addition of RHA. However, for longer curing periods and at 25 percent ash content, the results are similar. Hence, it can be assumed that, for alluvial silty soils of the A4 group, replacing 25 percent of cement with ash and a 14-day curing period produces strength almost the same as that produced by cement only.

Maximum Dry Density

The relationship between maximum dry density (AASHTO T99) and cement content is shown in Figure 16. For Soil B, density decreases with increasing cement content; for Soil A, density decreases up to 4 percent cement content, after which no change occurs.

Figure 17 shows the effect of addition of RHA on maximum dry densities of soil-cement mix for Soils A and B. Density decreases with increasing ash content. Because RHA has a

TABLE 3 RATIO OF UNCONFINED COMPRESSIVE STRENGTH OF CEMENT-STABILIZED SOIL (UC_c) TO UNTREATED SOIL (UC)

Soil Sample	Cement Content (%)	UC_c/UC		
		7 days	14 days	28 days
A	2	3.42	4.92	11.14
	8	9.71	11.73	15.90
	10	11.48	14.10	18.65
B	2	5.16	7.32	11.43
	8	9.14	10.93	14.28
	10	11.75	12.70	17.13

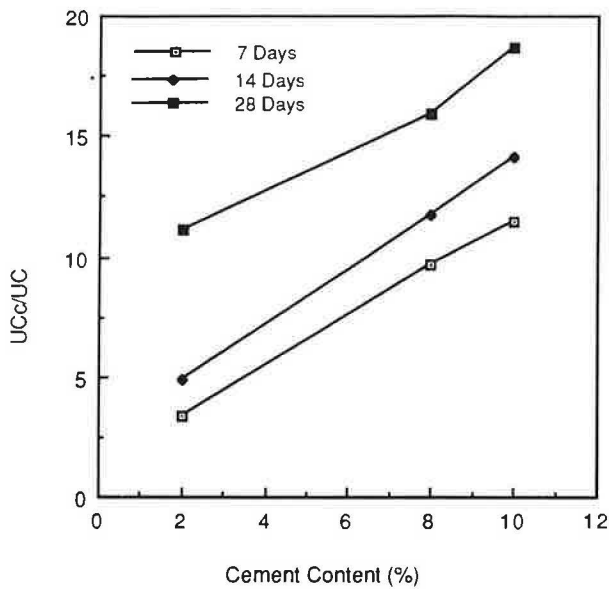


FIGURE 11 Strength ratio of cement-treated Soil B to untreated soil.

unit weight less than the soil, the presence of RHA in the soil-cement mix reduces the density.

Plasticity Indexes

The variation of the Atterberg limits and the plasticity index with the increments of cement contents is shown in Figures 18 and 19, respectively. The plastic limit and liquid limit increase with increasing cement content. The increase in plastic limit is appreciable, lowering the plasticity index at higher cement contents. These results agree with those reported by Ahmed (6). Figure 20 shows that addition of RHA initially decreases the liquid limit and plastic limit of cement-RHA-stabilized

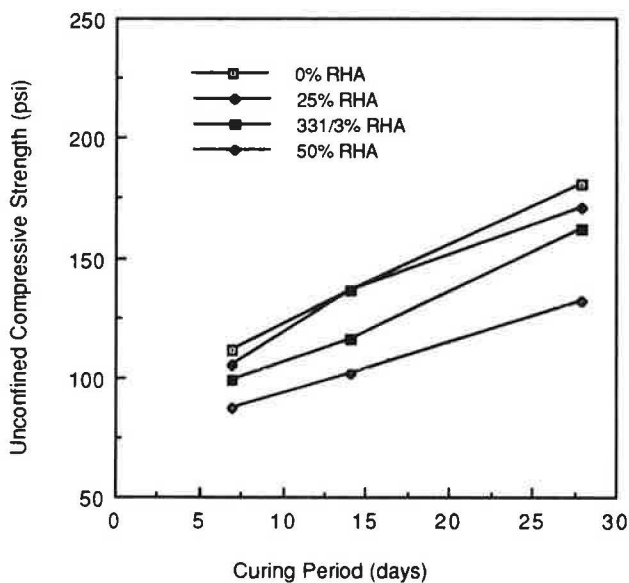


FIGURE 12 Effect of RHA replacement in cement on compressive strength of cement-RHA-treated Soil A.

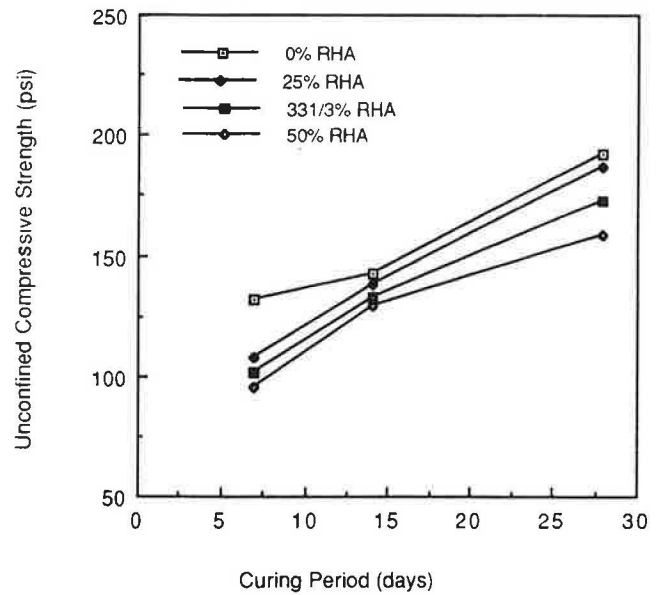


FIGURE 13 Effect of RHA replacement in cement on compressive strength of cement-RHA-treated Soil B.

soil. However, both increase at ash content greater than 33 1/3 percent. This change is pronounced for the liquid limit and results in an increase of the plasticity index (see Figure 21).

Properties of RHA-Stabilized Soil

An attempt was made to study the properties of soils stabilized only with RHA. Samples prepared by mixing different percentages of RHA to soil for unconfined compression and plasticity tests collapsed during curing. Results indicate that, like many types of pulverized fuel ash, RHA has no cementation value of its own.

CEMENT AND CEMENT-RHA STABILIZATION OF LOW-VOLUME ROADS

Local alluvial silty soils require a very high amount of cement to fulfill the PCA strength requirement for soil-cement stabilization. In Bangladesh, where domestic cement production does not meet the local demand and cement is costly, the soil-cement stabilization technique is uneconomical with such a large amount of admixture. However, the stabilization of alluvial silty soils with a small amount of cement (i.e., 2 percent) is promising. The addition of 2 percent cement produces an appreciable strength increase. This cement-modified soil can be used as an upgraded material for subgrade and subbase construction on low-volume paved roads in Bangladesh. A similar study in Singapore (16) has demonstrated that silty soils with 2 percent cement can be employed successfully for good subbase or subgrade construction, satisfying TRRL requirements.

RHA can be used with cement to achieve economy in the construction of low-volume roads. This study shows 25 percent of the cement can be replaced by RHA for stabilization. If a minimum 6 percent cement content is used for stabi-

TABLE 4 RATIO OF UNCONFINED COMPRESSIVE STRENGTH OF CEMENT-RHA-STABILIZED SOIL (UC_{RHA-c}) TO CEMENT-STABILIZED SOIL (UC_c)

Soil	Cement: RHA	UC_{RHA-c}/UC_c		
		7 days	14 days	28 days
A	3:1	0.945	1.0	0.948
	2:1	0.890	0.853	0.897
	1:1	0.789	0.746	0.730
B	3:1	0.820	0.960	0.973
	2:1	0.770	0.927	0.897
	1:1	0.720	0.904	0.823

Note: Total Admixture Content is 10%

zation, then the cement requirement with partial replacement by RHA would translate to 4.5 percent cement content.

Considerable savings can also be achieved by treating the local soils with an RHA-cement blend for earth road construction. The roads are expected to be more durable than those constructed with untreated soil, reducing annual maintenance cost and providing a stabilized base or subbase for stage construction of paved roads.

CONCLUSIONS

The important findings and conclusions drawn on the various aspects of this study can be summarized as follows:

1. The alluvial silty soils satisfy the durability criteria recommended by PCA at about 9 percent cement content. This value is well within the suggested range.

2. The silty soils fail to satisfy the minimum unconfined compressive strength criteria for the cement content at which the durability criteria is satisfied. Thus, the results do not support the implied assumption that the strength needs will automatically be met if the durability needs are satisfied. For the type of soils used in this study, a much higher cement content would be required to satisfy the strength criteria.

3. RHA can be blended with cement to stabilize silty soils. The results suggest that a total admixture content of 10 percent can be replaced with 7.5 percent cement and 2.5 percent RHA without impairing the durability or appreciably decreas-

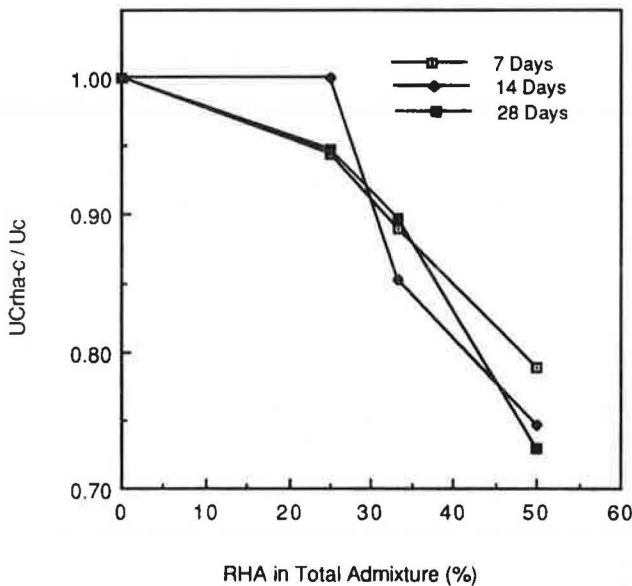


FIGURE 14 Strength ratio of RHA-cement-treated soil to cement-treated soil versus RHA content in total admixture for Soil A.

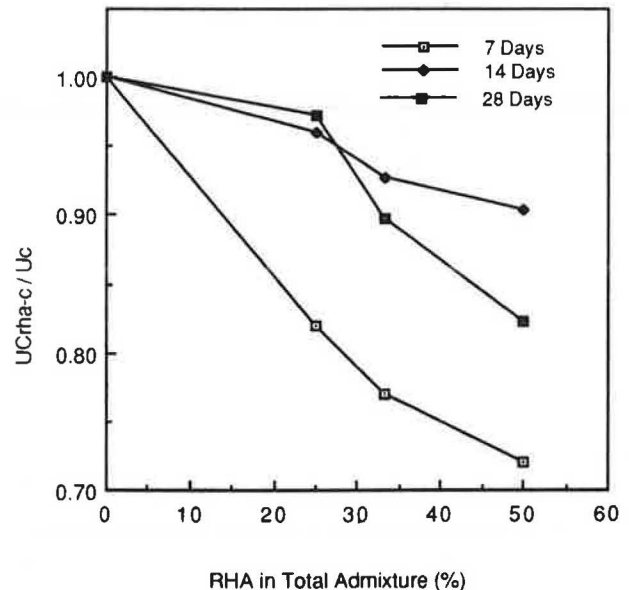


FIGURE 15 Strength ratio of RHA-cement-treated soil to cement-treated soil versus RHA content in total admixture for Soil B.

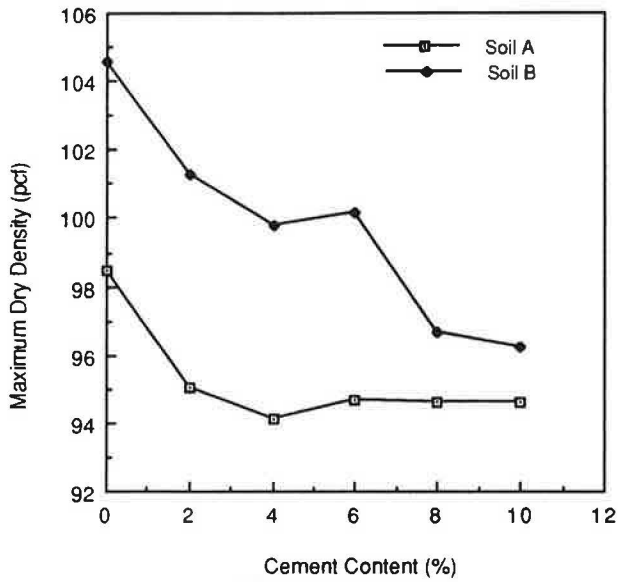


FIGURE 16 Effect of cement addition on dry densities of Soils A and B.

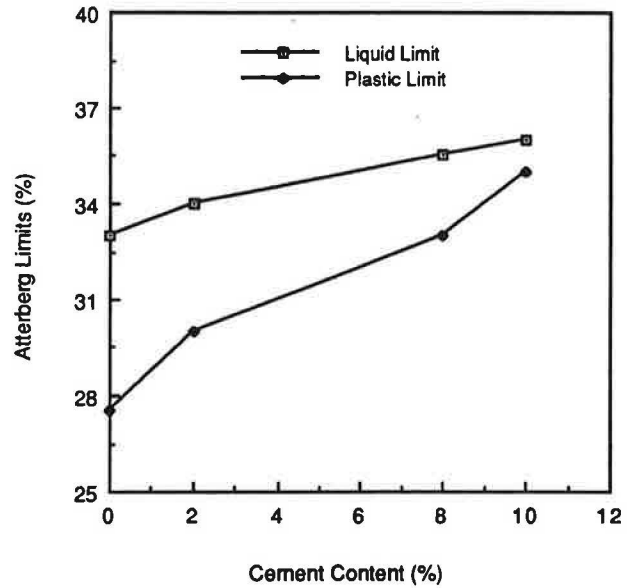


FIGURE 18 Effect of cement addition on Atterberg limits of Soil B.

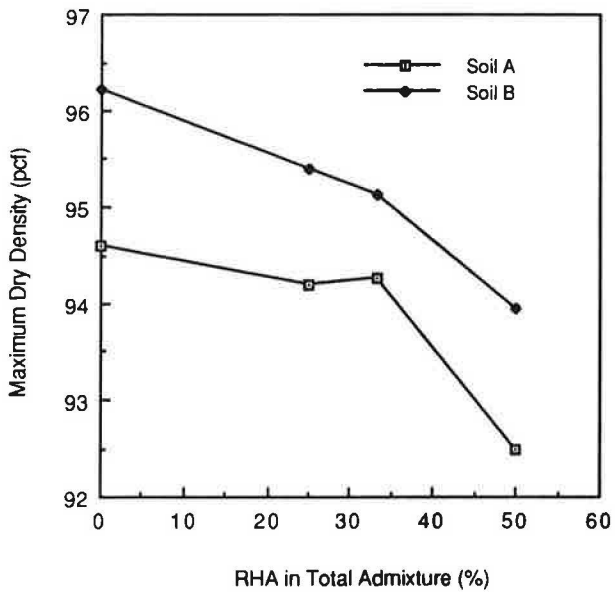


FIGURE 17 Effect of RHA addition on dry densities of cement-treated Soils A and B.

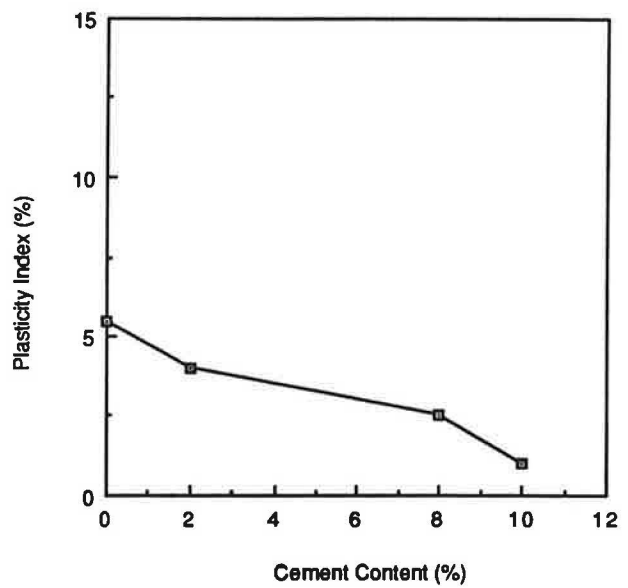


FIGURE 19 Effect of cement addition on plasticity index of Soil B.

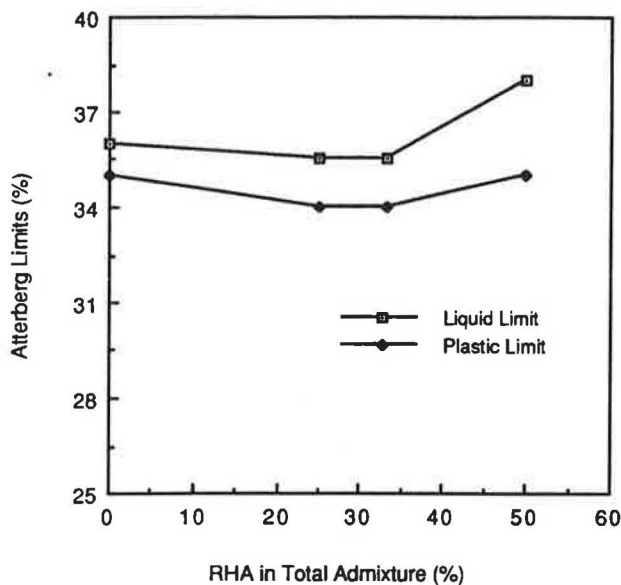


FIGURE 20 Effect of RHA-cement addition on Atterberg limits of Soil B.

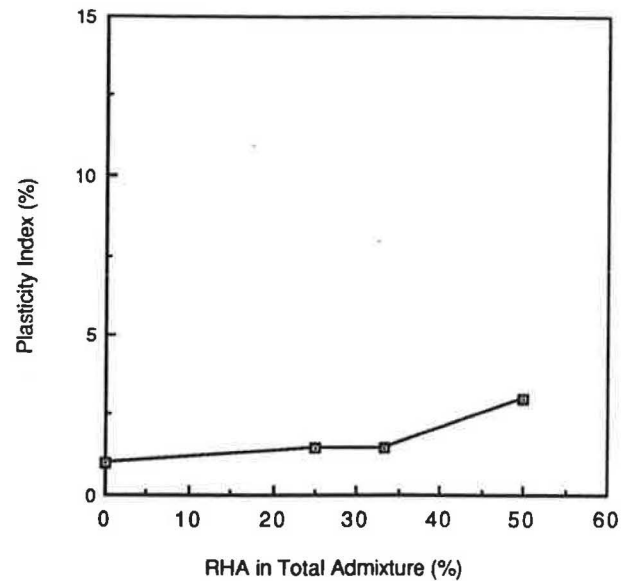


FIGURE 21 Effect of RHA-cement addition on plasticity index of Soil B.

ing the strength of such mixtures in comparison to those in which only cement is used.

4. A reduction in volume takes place during dry cycles of the wet-dry test with higher proportions of cement, whereas the addition of RHA results in an increase in volume on wetting. Silts show a decrease in maximum dry density when treated with cement. Cement-RHA-treated silty soils show a further decrease in dry density.

5. RHA cannot be used alone for stabilization of soil because of its lack of cementitious property. It can only be used as an admixture with other cementitious materials.

6. The soils showed an appreciable strength gain over untreated soil with addition of only 2 percent cement by weight. Silty soils treated with 2 percent cement can be used as a good subbase and subgrade material in low-volume paved-road construction. Earth roads stabilized with a cement-RHA blend are expected to be more durable than untreated earth roads, reducing annual maintenance costs and providing a good subbase or base for stage construction of paved roads.

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