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Stabilized soil incorporating combinations of rice husk ash, pond ash and cement

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Abstract. The paper presents the laboratory study of clayey soil stabilized with Pond ash (PA), Rice husk ash (RHA), cement and their combination used as stabilizers to develop and evaluate the performance of clayey soil. The effect of stabilizer types and dosage on fresh and mechanical properties is evaluated through compaction tests, unconfined compressive strength tests (UCS) and Split tensile strength tests (STS) performed on raw and stabilized soil. In addition SEM (scanning electron microscopy) and XRD (X-ray diffraction) tests were carried out on certain samples in order to study the surface morphological characteristics and hydraulic compounds, which were formed. Specimens were cured for 7, 14 and 28 days after which they were tested for unconfined compression tests and split tensile strength tests. The moisture and density curves indicate that addition of RHA and pond ash results in an increase in optimum moisture content (OMC) and decrease in maximum dry density (MDD). The replacement of clay with 40% PA, 10% RHA and 4% cement increased the strength (UCS and STS) of overall mix in comparison to the mixes where PA and RHA were used individually with cement. The improvement of 336% and 303% in UCS and STS respectively has been achieved with reference to clay only. Developed stabilized soil mixtures have shown satisfactory strength and can be used for low-cost construction to build road infrastructures.

Keywords: rice husk ash; OMC; MDD; cement; stabilization

1. Introduction

India produces an enormous amount of industrial waste like pond ash, fly ash etc. and agricultural waste like rice husk ash as by-products. The amount of waste material is increasing day by day with the increase in population. It is general practice to dump these waste materials on lands, which creates environmental and social problems. Reuse of these waste materials is one of the effective ways for minimising such problems. The bulk use of wastes like pond ash, rice husk ash, fly ash tire wastes etc. as admixture is now becoming popular in the construction of geotechnical structures. Researchers have shown that these materials can be used in the subgrade of roads, embankments of roads, as fill materials in retaining walls etc.

Huge quantities of fly ash and bottom ash are produced as by-products from coal based power plants all over the world. In some countries, such as India, the ash is usually disposed in ash ponds in the vicinity of plants. The ash ponds, when their capacity is exhausted, are abandoned, creating

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vast flat barren lands. In India, at present, millions of tons of pond ash are deposited in such abandoned ash ponds that cover up nearly 20,000 ha of land. Moreover, the leachates, emanating from the ash ponds, carry toxic elements and heavy metals that may lead to contamination of surface water and groundwater bodies, as well as soils.

Several attempts have been made to improve the engineering properties of pond ash by adding lime/cement by mechanical mixing. Kumar *et al*. (1999) gives the results of laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibres. The test results reveal that the inclusion of fibres in soils increases the peak compressive strength, CBR value, peak friction angle, and ductility of the specimens. Sarkar *et al*. (2012) reported improvement in California bearing ratio of pond ash with different percentage of cement. Bera *et al*. (2007) reported that with the increase in compactive efforts, MDD increases and at the same time OMC decreases. Chand and Subbarao (2007) presented the effects of lime stabilization on the strength and durability aspects of a class F pond ash, with a lime constituent as low as 1.12%, are reported. Lime contents of 10 and 14% were used, UCS increased with increase in lime content. Roy and chattopadhay. 2008 carried out experiments to study the effectiveness of utilization of RHA and pond ash for improving subgrade for road construction, their findings were as: addition of pond ash or RHA shows a considerable effect on compaction characteristics of alluvial soil. MDD of mixed soil decreases with increase in added percentage of either of pond ash or RHA and OMC increases. Ghosh (2010) presents the laboratory test results of a Class F pond ash alone and stabilized with varying percentages of lime (4, 6, and 10%) and Phosphogypsum (0.5, and 1.0), to study the suitability of stabilized pond ash for road base and sub-base construction.

Rice husks are the shells produced during de-husking operation of paddy, which varies from 20% (Mehta 1986) to 23% (Della *et al*. 2002) by weight of the paddy. The rice husk is considered as a waste material and is being generally disposed of by dumping or burning in the boiler for processing paddy. The burning of rice husk generates about 20% of its weight as ash (Mehta 1986). Silica is the main constituent of rice husk ash (RHA) and the quality (% of amorphous and un-burnt carbon) depends upon the burning process (Nair *et al*. 2006). The RHA is defined as a pozzolanic material (ASTM C 168, ASTM 1997) due to its high amorphous silica content (Mehta 1986). In India, the annual production of paddy is about 100 million tonnes, thereby generating more than 4 million tonnes of RHA (Ramakrishna and Pradeep Kumar 2008).

Rice husk ash cannot be used alone for stabilization of soil due to lack of cementitious properties (Ali *et al*. 1992). So it is used along with a binder like Lime, cement, lime sludge, Calcium chloride etc. for stabilization of soil (Muntohar and Hantoro 2000, Ali *et al*. 1992, Ramakrishna and Pradeep Kumar 2006, Basha *et al*. 2005, Chandra *et al*. 2005, Sharma *et al*. 2008, Aziz *et al*. 2015, Canakci *et al*. 2015)

The use of RHA and Pond Ash in soil stabilization can lead to low-cost construction and can provide an environmentally friendly means of their disposal. Increased use of such materials would reduce the use of cement and also represent savings in energy and greenhouse gas emissions.

2. Scope of the present study

The paper presents the laboratory study on clayey soil stabilized with pond ash, rice husk ash and their combination. Test specimens were subjected to compaction tests, unconfined compre-ssion strength tests, and split tensile strength tests. Specimens were cured for 7, 14, and 28 days after which they were tested for unconfined compression tests and split tensile tests. This paper presents the details and results of the experimental study and the conclusions from the study.

3. Experimental investigation

3.1 Material

3.1.1 Soil

Soil used in this study is kaolin clay obtained from locally available market. According to Unified Soil Classification System (USCS) soil is classified as CL (clay with low plasticity). The index properties of soil are presented in the Table 1.

3.1.2 Pond ash

The pond ash used in this investigation was collected from the Guru Nanak Dev Thermal Power Plant, Ropar district Punjab, India. Pond ash was collected by excavation of recent fills up to a depth of 1 m from the surface. The pond ash is categorized as Class F type as per ASTM specification C 618-12 (2012). The ash collected was found to be a uniformly graded material with more than 86% particles in the range of 425 μ to 75 μ. The basic properties of pond ash are as given in Table 2 and the chemical composition of the pond ash is presented in Table 3. However the major constituent of pond ash is SiO_2, while the amount of CaO is very less. As per ASTM C

Table 1 Properties of clay

Properties	Values
Specific gravity (G)	2.65
Liquid limit (%)	43
Plastic limit (%)	19
Plasticity index (I_p)	24
Optimum moisture content (%)	16.5
Maximum dry density (g/cc)	1.75

Table 2 Properties of pond ash

Physical parameters	Values
Colour	Light grey
% Particle (< 75 μ size)	41.6
% Particle (75 μ to 425 μ size)	44.6
% Particle (425 μ to 2 mm size)	12.2
% Particle (2 mm to 4.75 mmsize)	1.6
Shape	Rounded/sub-rounded
Specific gravity, *G*	2.10
LL and PL	Non- plastic
Optimum moisture content (%)	26
Max. dry density (g/cc)	1.32

Table 3 Chemical composition of pond ash

Oxide compounds	Contents (%)
Calcium oxide (CaO)	4.15
Silica (SiO_2)	53.65
Alumina (Al_2O_3)	22.99
Iron oxide (Fe_2O_3)	8.76
Magnesia (MgO)	1.4
Others	
L.O.I	10.22

618-08, pond ash is classified as F-Class pond ash.

3.1.3 Rice husk ash

Rice husk was considered as valueless by-product of rice milling. At the mills, disposal of the hulls is achieved by burning them in heaps near the mills. It is produced by rice mill industry while processing rice from paddy. About 20-22% rice husk is generated from paddy and about 25% of this total husk become ash when burn. It is non – plastic in nature. Its properties also varied depending on its burning temperature.

RHA has a good pozzolanic property. RHA was collected from local rice mill. It chemical and physical properties are shown in the following Table 4. However the chemical characteristics of the aforementioned RHA have done and it is mostly comprised by SiO_2.

3.1.4 Ordinary portland cement (OPC-43 GRADE)

The physical properties of cement are shown in Table 5. For this study the Ordinary Portland cement of SHREE ULTRA TECH Cement Company was used, which was available in local market.

Table 4 Chemical and physical properties of rice husk ash

Chemical composition	
Oxide compounds	Content (%)
Calcium oxide (CaO)	3.4
Silica (SiO_2)	87.3
Alumina (Al_2O_3)	2.9
Iron oxide (Fe_2O_3)	0.0
Magnesia (MgO)	3.1
Sodium oxide (Na_2O)	0.8
Potassium oxide (K_2O)	2.9
Physical composition	
Specific gravity	1.98
Optimum moisture content (OMC)	60 %
MDD (g/cc)	0.879

Table 5 Physical properties of cement

Physical properties	Value
Fineness	3
Specific gravity, *G*	3.15
Standard Consistency, %	38
Initial setting time, minute	30
Final setting time, minute	600
Soundness (Cement Expansion, mm)	3

Table 6 Stabilizer combination scheme for soil

Combinations	Designation
	(Single stabilizers)
0, 5, 10, 15 and 20% RHA	0RHA, 5RHA, 10RHA, 15RHA, 20RHA.
0, 10, 20, 30, 40 and 50% POND ASH	0PA, 10PA, 20PA, 30PA, 40PA, 50PA.
	(Mixed stabilizers)
0%RHA+ 0%POND ASH	0RHA0PA
5%RHA+ 45%POND ASH	5RHA45PA
10%RHA+ 40%POND ASH	10RHA40PA
15%RHA+ 35%POND ASH	15RHA35PA
20%RHA+ 30%POND ASH	20RHA30PA

3.2 Experimental procedure

3.2.1 Combination schemes for stabilized soil mixtures

A comprehensive series of laboratory tests were conducted on the selected clayey soil stabilized with various percentages and combinations of the stabilizers rice husk ash and pond ash. The tests performed include Specific gravity, grain size analysis, XRD, SEM, modified Proctor compaction test, unconfined compressive strength test and split tensile strength test. Table 6 presents a summary of stabilized soil with various stabilizer combinations. The percentages used of RHA were 0, 5, 10, 15 and 20% and of PA were 30, 35, 40 and 45% of total mass of the mixture with different percentages of cement as 0, 2 and 4%.

3.2.2 Specimen preparation and testing procedures: Overview

An amount of soil was mixed with Pond Ash, Rice husk ash and Cement to yield stabilized soil specimens. In the research reported in this paper, the amount of cement used was 0, 2 and 4%. All the specimens were prepared to the maximum dry density (MDD) and optimum moisture content (OMC), and tested after 0, 7, 14 and 28-day moist-curing period.

The general expression for weight of dry sample (W) was taken as

$$W = Ws + WP + WR + WC \tag{1}$$

Where W_S, W_P, W_R, W_C = weight of soil, pond ash, rice husk ash and cement respectively.

3.2.3 Specimen preparation and testing procedures

Unconfined compression and split-tensile tests

The unconfined compressive strength (UCS) test apparatus was employed in the tests. Samples were shaped in a mould with a length of 76 mm and an inner diameter of 38 mm. The specimens were prepared at the state of MDD and OMC. To ensure uniform compaction, the required quantity of the material was placed inside the mould in three layers and compacted statically by applying compressive pressure from a hydraulic jack. Three identical specimens were used to determine the unconfined compressive strength and split tensile strength. To control the variation of the test results, especially for the UCS and split-tensile tests, the difference of the three values should not be greater than 10%. If the difference of the values between the specimens was greater than 10%, then other specimens were prepared and tested.

The unconfined compression tests and the split-tensile tests were carried out in accordance with ASTM D2166-98 and ASTM C496-96, respectively. After the curing period and before testing, the mass and dimension of specimen were recorded. The tests were performed on a 25-kN testing machine. A force was applied until the specimens reach a failure. The loading rate was approximate 1.14 mm/min. The split tensile strength was calculated as

$$T = \frac{2P\text{max}}{\pi LD} \tag{1}$$

Where T = split tensile strength; Pmax = maximum applied load; and L and D = length and diameter of the specimen, respectively

SEM/EDS observations for surface characterization and elemental composition

The surface morphological features and presence of different elements present in the samples were examined using Scanning Electron Microscopy (JEOL – JSM 6510). The samples were coated with conductive coating prior to image observation.

XRD analysis for hydration behaviour

The presence of different phases present in samples was analysed using XRD (PANalytical XPERT – PRO Diffractometer) in 2θ range between 10° to 70°. The samples to be analysed were thoroughly ground to fine powder prior to characterization

4. Results and discussion

Particle size distribution tests, tests for characterization of surface morphology using SEM, hydration behaviour using XRD, modified Proctor compaction test, unconfined compression tests and split tensile strength tests were performed on the mixtures of pond ash-rice husk ash, clay and cement. Results obtained from these tests are presented in the following sections.

4.1 Gradation of soil with admixtures

The gradation of the sample, were determined using ASTM D422. Fig. 1 shows the grain size distributions for clay, Rice husk ash and bottom ash used, as their respective mixtures. Generally, the Pond ash was well graded, ranging from mostly silt to fine sand sizes. A majority of the sizes occurred in a range between 0.001 and 0.075 mm. The shapes of the gradation curves indicated

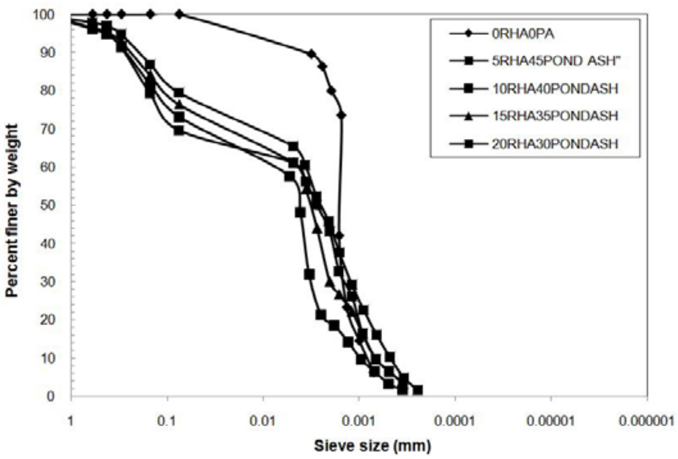
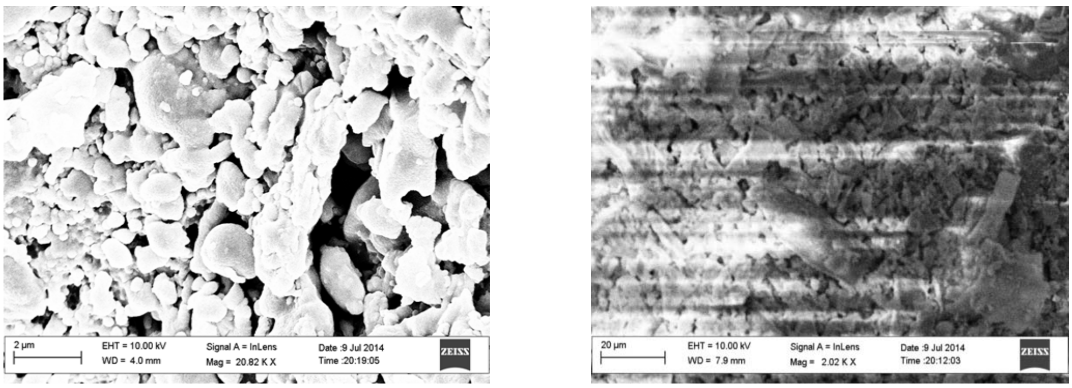


Fig. 1 Particle size distribution of pond ash, rice husk ash-soil in various combinations

Table 7 Basic grain size indices of various combinations

Mix combinations	Cu (Coefficient of Uniformity)	Cc (Coefficient of Curvature)
0PA0RHA	0.66	1.5
5RHA45PA	10	0.81
10RHA40PA	9	1.2
15RHA35PA	8.5	1.17
20RHA30PA	7.5	1.875

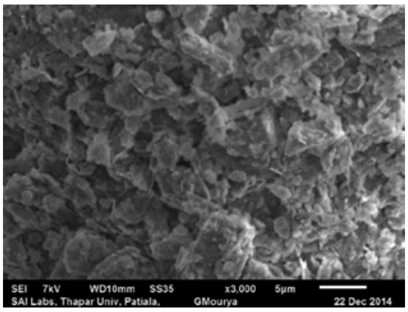


(a) (b)

Fig. 2 Scanning electron micrographs (SEM) of: (a) pond ash; and (b) rice husk ash

that the size distributions became better graded with increasing bottom ash content in the ash mixtures. The basic grain size indices of various combinations are presented in Table 7.

Figs. 3(a) and (b) represent the surface morphology of Soil + PA mixture after 7 days curing, in



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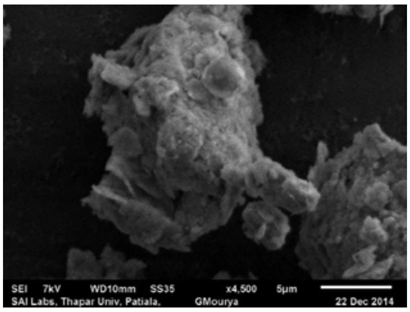

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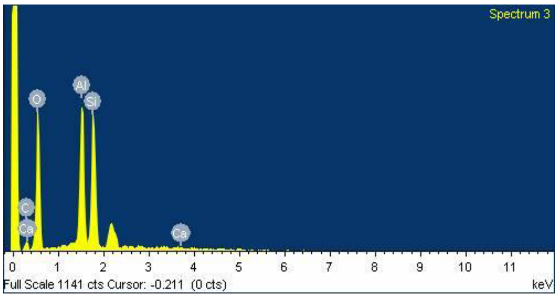
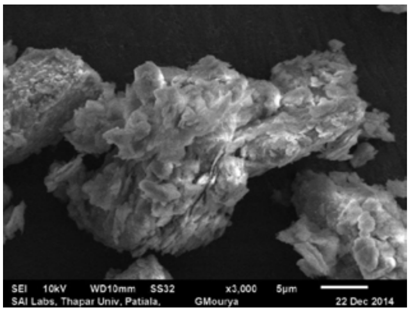


(c)

Element	Percentage
C	13.85
O	56.84
Al	13.49
Si	15.74
Ca	0.07

Fig. 3 (a) SEM image of Soil + PA at × 3,000; (b) SEM image of Soil + PA at × 4,500; (c) EDS spectrum of Soil + PA and its Elemental composition (table on right) after 7 days curing



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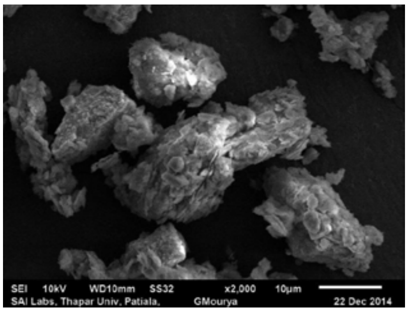

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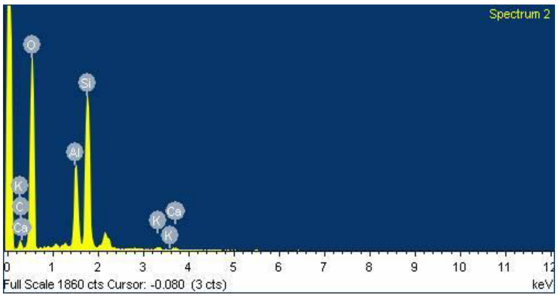
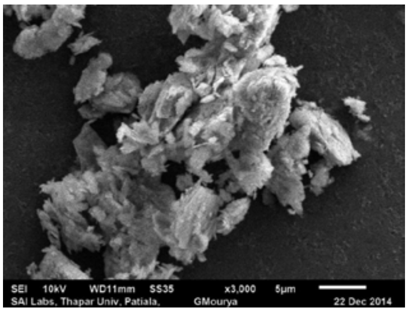


Element	Percentage
C	4.41
O	66.97
Al	9.03
Si	18.76
Ca	0.37
K	0.46

Fig. 4 SEM images of Soil + RHA after 7 Days curing (a) ×3,000 (b) × 2,000 (C) EDS spectrum of Soil + RHA and its Elemental composition (table on right) after 7 days curing



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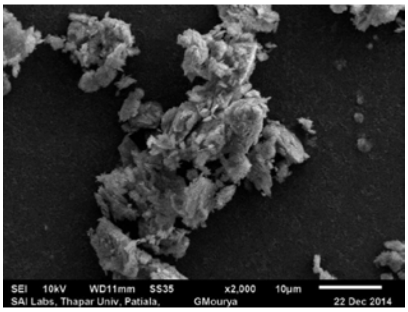

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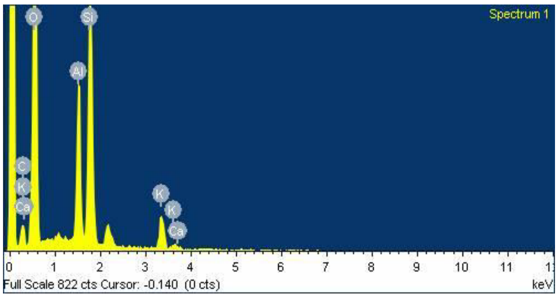
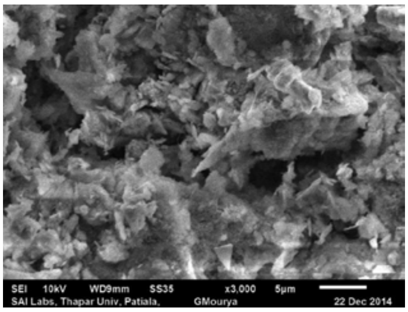


Element	Percentage
C	1.42
O	72.5
Al	7.14
Si	16.13
Ca	0.12
K	2.43

Fig. 5 SEM images of Soil + PA + RHA after 7 days curing (a) ×3,000 (b) ×2,000 (C) EDS spectrum of Soil + PA+ RHA and its Elemental composition (table on right) after 7 days curing



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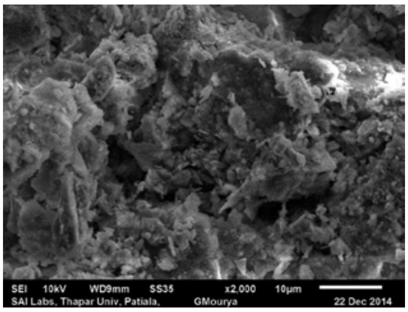

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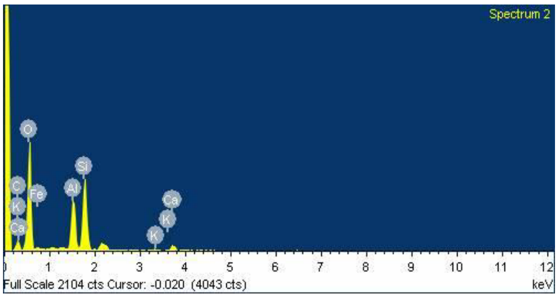

Element	Percentage
C	1.42
O	72.5
Al	7.14
Si	16.13
Ca	0.12
K	2.43

Fig. 6 SEM images of Soil + PA + RHA + Cement after 7 days curing (a) ×3,000 (b) ×2,000 (c) EDS spectrum of Soil + PA + RHA + cement and its Elemental composition (table on right) after 7 days curing

which the platy shaped particles of kaolin clay (soil) and spherical or rounded particles of PA were observed. Figs. 3(c) and (d) respectively presents the EDS spectrum and elemental composition of soil +PA. Figs. 4(a) and (b) show the SEM images of Soil + RHA mixture after 7 days, indicating the similar palatines of Kaolin clay particles as observed in Fig. 3, with additional particles of RHA having irregular surface morphology. Figs. 4(c) and (d) respectively presents the EDS spectrum and elemental composition of soil +RHA. Figs. 5(a) and (b) show the SEM observations of Soil + PA + RHA mixture which reveals the three different types of particles corresponding to platy Kaolin clay, spherical PA and irregular RHA. Figs. 5(c) and (d) respectively presents the EDS spectrum and elemental composition of soil +PA+ RHA. The effect of addition of cement as additional stabilizing agent was observed in Fig. 6. The SEM results (Figs. 6(a) and (b)) show the formation of huge amounts of C- S- H (Calcium – Silicate – Hydrate) phase in form of gel, along with elongated crystalline structures. This hydration is attributed to the formation of pozzolanic reaction and additional stabilization of clay. Figs. 6(c) and (d) respectively presents the EDS spectrum and elemental composition of soil +PA+ RHA+ cement.

4.2 Specific gravity

Specific gravity is determined using ASTM D854 (2000) (Method A). The values of specific gravity of Soil, Rice Husk ash and pond ash and their Mixes are summarized in Table 2. These values ranged from 2.28 to 2.57, indicating a large variation between ash mixes. The wide range in specific gravity can be attributed to two factors: (1) Chemical composition; and (2) Presence of hollow Pond ash particles with porous or vesicular textures. The low specific gravities of Pond ash and are explained by their low iron oxide contents. Different amounts of hollow particles present in Pond ash also cause a variation in apparent specific gravity. Obviously, a Pond ash containing a large percentage of hollow particles would have a lower apparent specific gravity than one with mostly solid particles. The low specific gravity of rice husk ash is due to the present of hollow particles in rice husk ash also causing a variation in apparent specific gravity.

It can be seen that addition of Pond ash and Rice husk ash decreases the specific gravity of the soil. This decrease in specific gravity can be due to the lower value of specific gravity of Pond ash and RHA. It can be seen that rate of decrease in specific gravity due to RHA is high as compared to PA. It is due to the reason that RHA has lower specific gravity than pond ash.

4.3 XRD results of the specimens

Fig. 7 shows the comparison of XRD pattern of Soil + PA and Soil + PA + Cement after 7 days of curing. It can be observed that treatment of kaolin clay (soil) with cement as an additional stabilizing agent reduces the relative quantities of kaolinite (K) and Quartz (Q). This can be

Table 8 Specific gravity of soil and soil, pond ash and rice husk ash mixes

Designation	Specific gravity
0RHA0PA	2.65
5RHA45PA	2.49
10RHA40PA	2.43
15RHA35PA	2.35
20RHA30PA	2.28

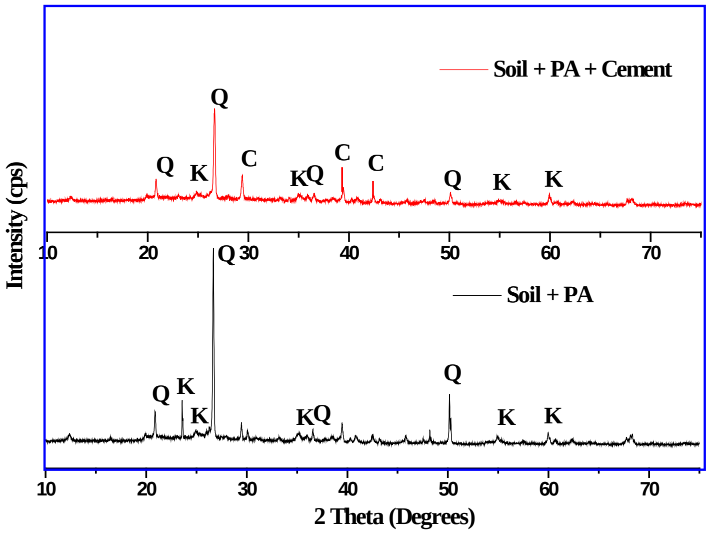

Fig. 7 XRD Patterns of clay treated with pond ash

confirmed from the disappearance of peaks or the fall in the intensities of the corresponding peaks. Pozzolanic action of cement can be visualized from the simultaneous appearance of new peaks which are attributed to the presence of pozzolanic product i.e., Calcite ($CaCO_3$).

Fig. 8 shows the comparative XRD spectra of Soil + RHA and Soil + RHA + Cement, after 7 days of curing. The stabilizing activities of both RHA and cement are indicated by the disappearance of kaolinite and Quartz in a similar manner as observed in case of PA. However, the pozzolanic action is rapid in case of RHA and Cement as stabilizers as observed from high intensities of pozzolanic product $CaCO_3$ and reduced intensities of Quartz peaks.

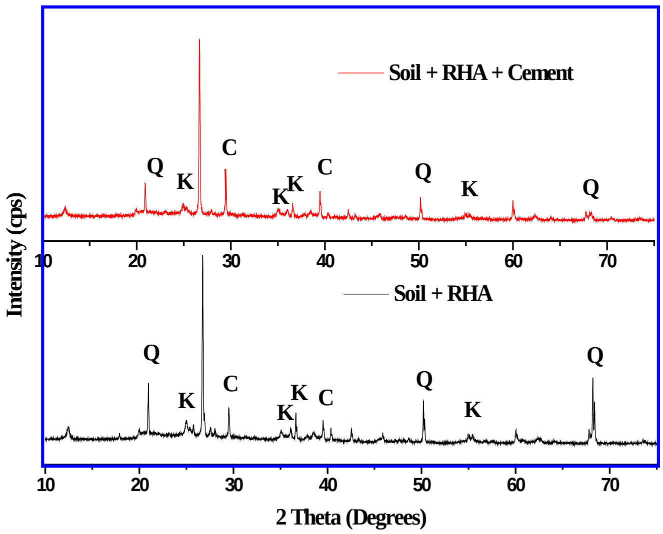

Fig. 8 XRD Patterns of clay treated with rice husk ash

As revealed from Fig. 9, the X- Ray Diffraction patterns of the untreated clay (A) and treated clay samples (B-D), it was observed that the untreated clay showed the major presence of the clay mineral i.e., Kaolinite ($Al_2Si_2O_5\ (OH)_4$); at peak positions of $2\theta = 24.8°$, 26.6° and 60.5° ($d = 3.58$ Å, 3.34 Å and 1.52 Å respectively); and characteristic peaks corresponding to the presence of Quartz (SiO_2), at $2\theta = 20.8°$ and 50.1° ($d = 4.25$ Å and 1.8 Å) (Basha *et al*. 2005, Solanki and Zaman 2012). After the subjection to the stabilization process using various treatments in different proportions after curing the sample for 7 days, it was observed that there is a reduction in the peak intensities corresponding to Quartz as well as Kaolinite. This could be attributed to the cementitious reactions taking place between the additive (stabilizing material) and the basic clay minerals. The percentage reduction for the different treated samples, however, differs significantly. As the amount of stabilizing material was increased, it could be figured out that the peak intensities of the clay minerals decreased remarkably. Moreover, XRD patterns of all the stabilized specimens revealed additional peaks of Calcite ($CaCO_3$); peak positions at $2\theta = 27.1°$ and 39.4° (d = 3.30 Å and 2.28 Å), which is formed as a result of the cementitious/ pozzolanic reactions. For

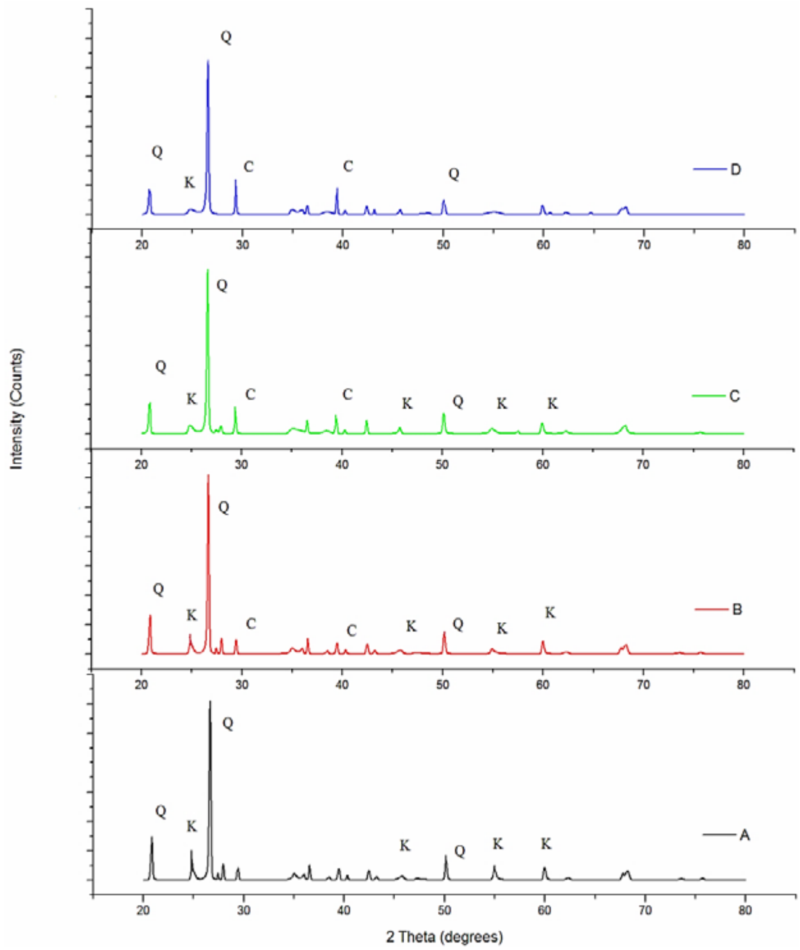

Fig. 9 XRD Patterns of Untreated Clay (A), treated clay with: (i) PA, RHA and 0% Cement (B); (ii) clay with PA, RHA and 2% Cement (C); (iii) clay with PA, RHA and 4% Cement (D)

the treated clay containing maximum percentage of the stabilizing material, the Quartz as well as Kaolinite peaks almost start disappearing. On the other hand, Calcite peaks are prominent for this treated clay material.

4.4 Compaction test

The tests were performed as per ASTM D1557-09 specifications for modified Proctor compaction tests. Modified Proctor compaction test were carried out on the soil-rice husk ash - cement mixture, soil-pond ash-cement mixture and soil-pond ash-rice husk ash-cement mixtures proportions. The dry weight of total mixture (*W*) was taken as per Eq. (1). The compaction tests were performed for various combinations of soil rice husk ash-pond ash-cement mixtures as detailed in Table 6. Figs. 10-11 present the variation of dry density with rice husk ash and pond ash content stabilized with clay. The maximum dry density decreased and the optimum moisture

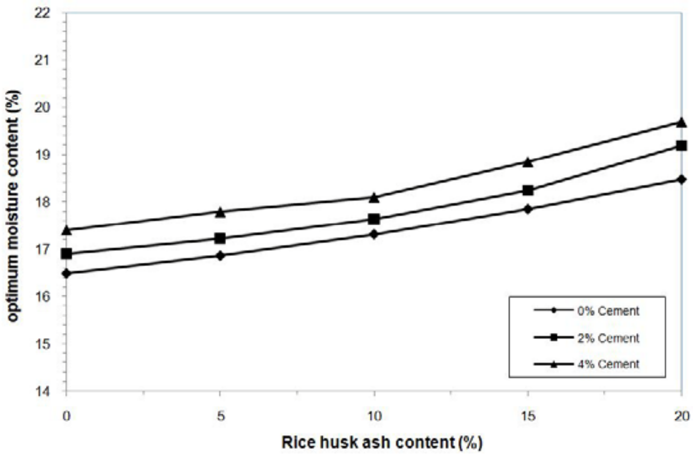

Fig. 10 Optimum moisture content versus rice husk ash (%) with different (%) of cement

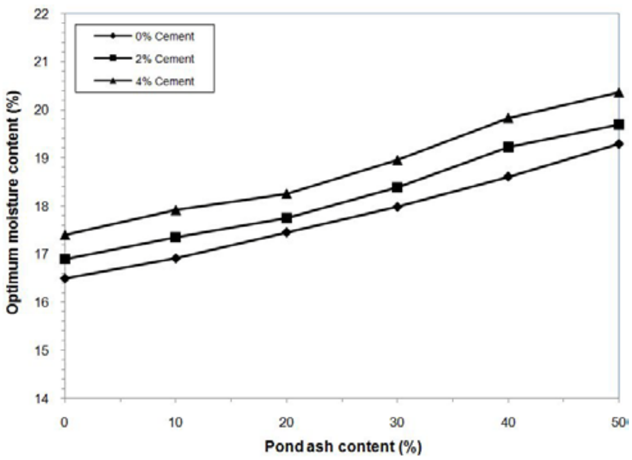

Fig. 11 Dry density versus Pond ash (%) with different % of cement

content increases with the increasd of RHA content from 0% to 20% and PA content from 0 % to 50%. Similar behaviour was also observed in the case of lime, rice husk ash, and fly ash-stabilized clayey soils in other research studies (Rahman 1986, Al-Rawas *et al*. 2005, Kaniraj and Havanagi 1999, Senol *et al*. 2006).

It can be observed from Figs. 10-12 that optimum moisture content increased with the increase in the combine dosage of RHA and PA in mix mode stabilization. The increase in optimum moisture content can be attributed to the increase in the pozzolanic reaction of RHA and pond ash with the soil constituents tends to increase the optimum moisture (Anwar Hossain 2011). The increase in optimum moisture content with the addition of cement is attributed to the extra water required for higher fineness and subsequent enhanced hydration.

From Figs. 13 and 14, it can be observed that with increase in cement content, the maximum dry density of soil-cement mixes decreased and optimum moisture content increased. The fall in density is due to quick reaction of cement with the soil and brings changes in Base Exchange

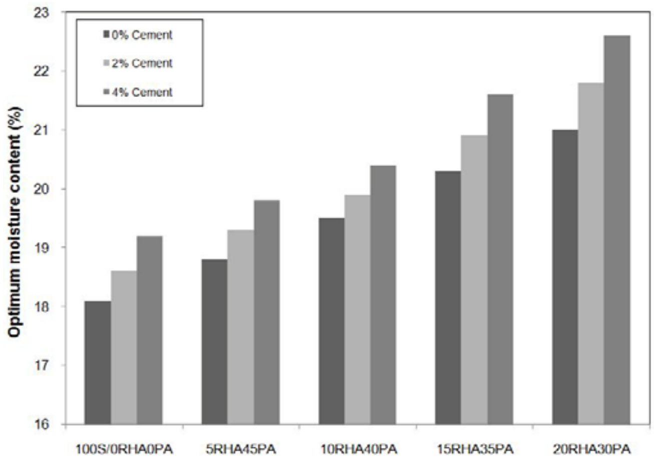

Fig. 12 Optimum moisture content versus RHA (%) and PA (%) mix with different (%) of cement

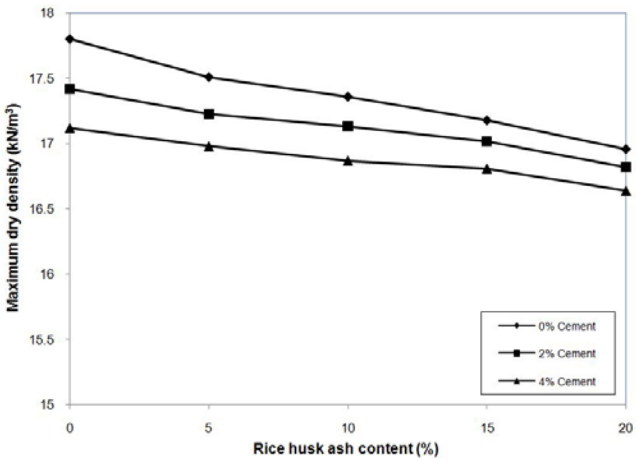

Fig. 13 Dry density versus rice husk ash content (%) with different % of cement

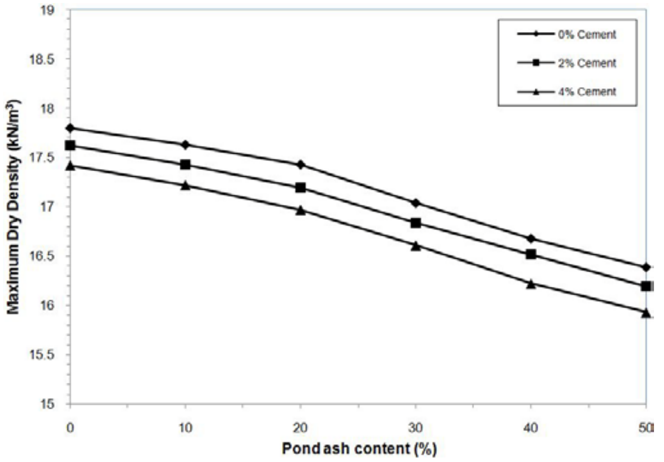

Fig. 14 Dry density versus pond ash content (%) with different % of cement

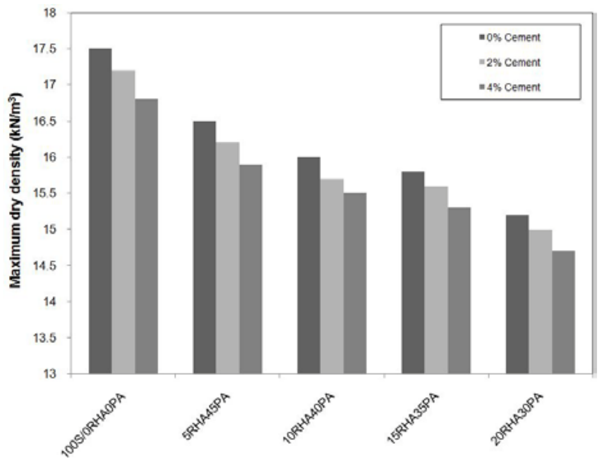

Fig. 15 Dry density versus RHA (%) and PA (%) with different % of cement

aggregation and flocculation, resulting in increased void ratio of the mix leading to a decrease in the density of the mix. The increase in optimum moisture content is probably on account of additional water held within the flocs resulting from flocculation due to cement reaction.

With the combine dosage of PA and RHA in mix mode stabilization, there is further decrease in the Maximum dry density and increase in the optimum moisture content. The presence of RHA and PA having a relatively low specific gravity may be the cause for this reduced dry density (Ali *et al*. 1992, Jha and Gill 2006, Alhassan 2008).

Table 9 shows the variation of MDD and void ratio for various mix combinations. Table shows that the MDD decreased with the increase in the percentage of RHA, but void ratio decreases up to 10% RHA content, but after that with the increased in the RHA content void ratio also increased. From these it can be concluded that the gradation of mix 10RHA40PA is the best as compared to the other mix combination. It shows that high compacted structure can be achieved with mix 10RHA40PA.

Table 9 Variation of MDD and void ratio for various mix combinations

Mix	MDD (γd)	Void ratio (e)
0RHA0PA	1.75	0.543
5RHA45PA	1.62	0.537
10RHA40PA	1.604	0.50
15RHA35PA	1.58	0.51
20RHA30PA	1.54	0.52

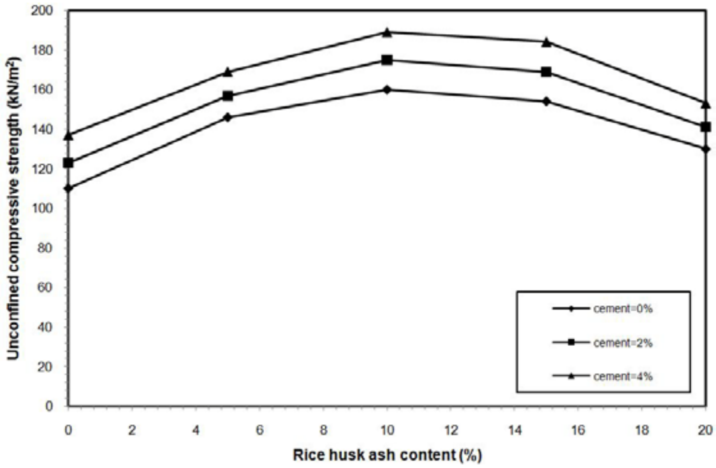

Fig. 16 Variation of UCS with percentage of rice husk ash content

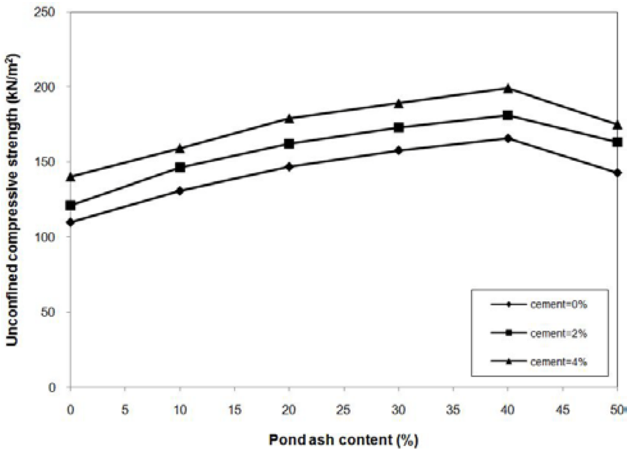

Fig. 17 Variation of UCS with percentage of pond ash content

4.5 Unconfined compressive strength test

Figs. 16 and 17 show the development of the unconfined compressive strength of stabilized soils with various percentages of RHA and PA. In general, the compressive strength increased with

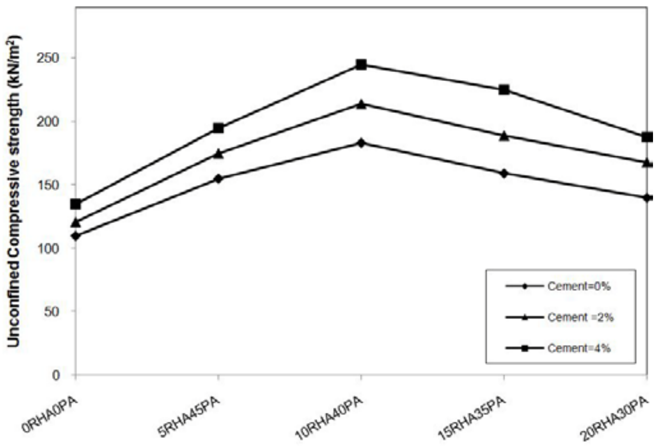

Fig. 18 Variation of UCS with different mixes at different percentage of cement

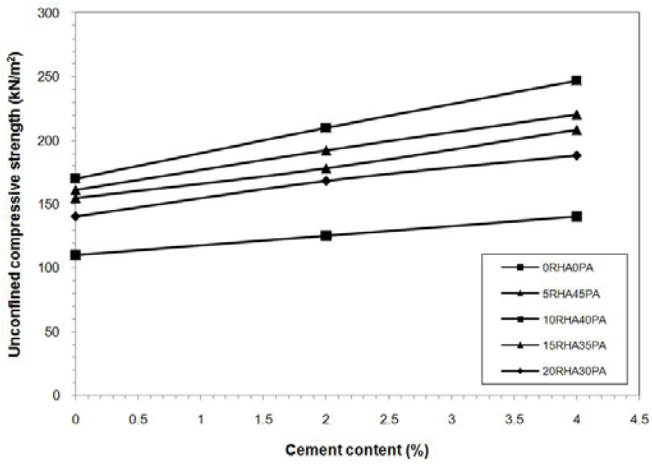

Fig. 19 Variation of UCS with different mixes at different percentage of cement content

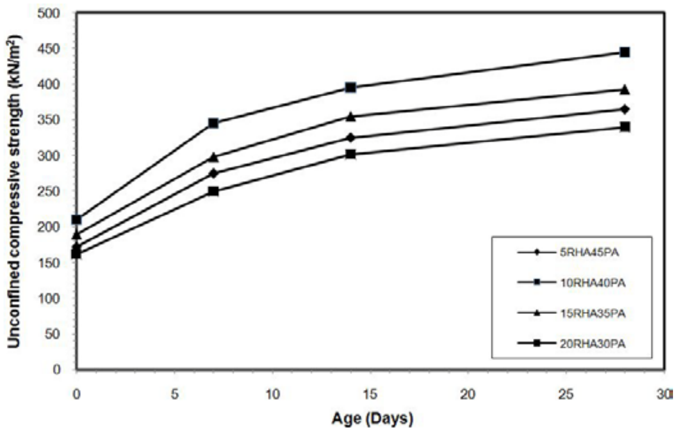

Fig. 20 Variation of UCS with curing period at different mix combinations with 2% cement

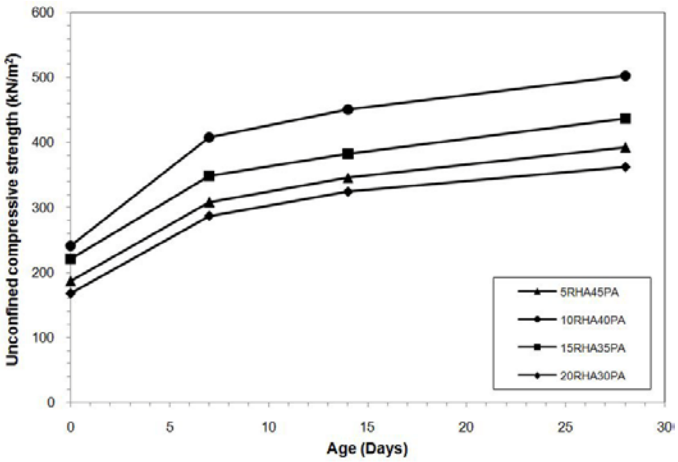

Fig. 21 Variation of UCS with curing period for different mix combinations with 4% cement

the increase in stabilizer content. The compressive strength of mix 10 RHA is 189 kPa, compared to 170 kPa of mix 40 PA. The effect of combining RHA and PA in mixed mode of stabilization is shown in Fig. 18. Stabilizer combinations with higher dosages produced higher compressive strength. The combination of stabilizers with RHA and PA produced higher compressive strength than single stabilizer. The compressive strength of combination mode stabilized soils ranged between 140 and 240 kPa. The increase in the strength may be due to the improvement in the gradation of the mix, which can be seen from the particle size distribution curve (Fig. 1).

The results of UCS tests on combination of RHA and Pond Ash stabilized Clay treated with different percentage of cement are shown in Figs. 18 and 19. It was observed that by addition of 10% RHA and 40% POND ASH, the UCS of soil was maximum, whereas it decreased thereafter. The initial increased in the UCS with addition of RHA and PA is attributed to the formation of cementitious compounds between the Ca(OH)2 present in the soil and the pozzolana present in the RHA and PA. The decreased in the UCS values after addition of 10% RHA and 40% PA may be due to formation of weak bonds between the soil and the cementitious compounds formed (Alhassan 2008). Similar results are reported by several other researchers (Brooks 2009, Ali *et al.* 1992, Muntohar 2009, Jha and Gill 2006, Alhassan 2008).

Figs. 20 and 21 present the effect of curing on the unconfined compression test samples, showing that the strength increased as the curing period increased. In addition, it can be observed that the unconfined compressive strengths of pond ash, rice husk ash-soil-cement mixtures after 7, 14, and 28 days of curing period are always higher than those of respective pond ash, rice husk ash- soil samples. The higher strength of soil-pond ash-rice husk ash-cement stabilized soil as compared to natural soil is a result of the time-dependent cementing and pozzolanic reactions respectively (Rahman 1986, Miller and Azad 2000). Thus, the strength of the stabilized soil increases as the curing duration increases.

4.6 Split tensile strength test

The splitting tensile strength increased with the increase of stabilizer content (Figs. 22 and 23). The RHA-based stabilized soils show higher tensile strength than their PA counterparts similar to that observed in the case of compressive strength (Figs. 22 and 23). For single mode stabilization,

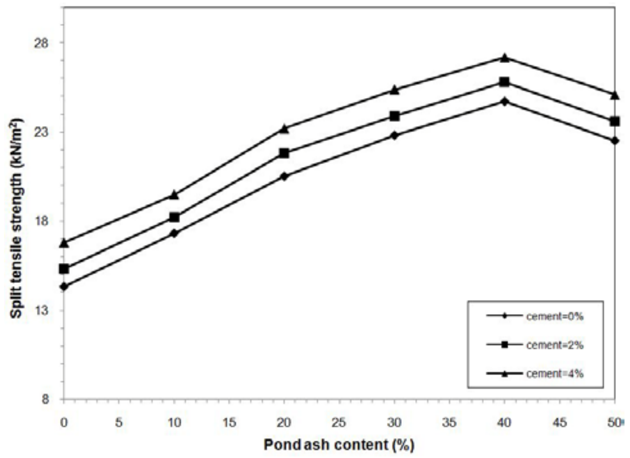

Fig. 22 Variation of STS with pond ash content (%) at different cement contents

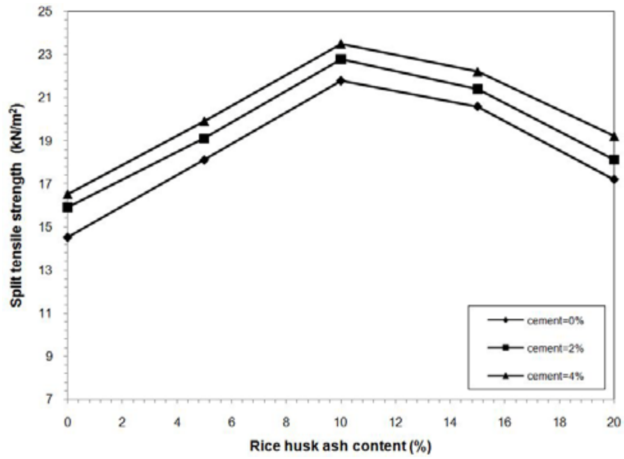

Fig. 23 Variation of STS with rice husk ash (%) at different cement contents

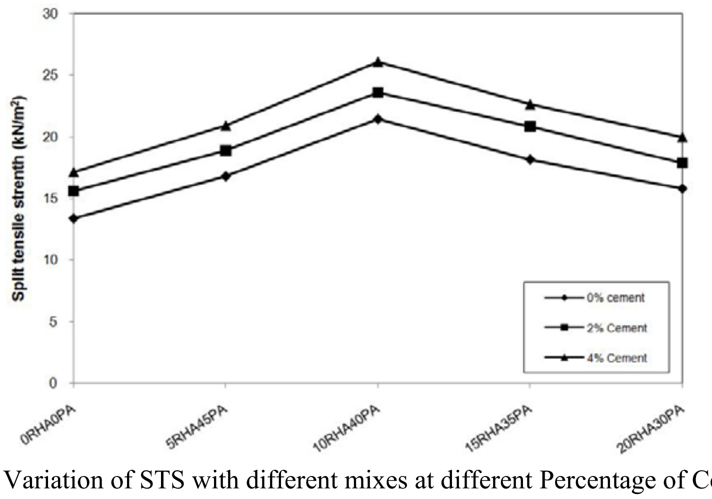

Fig. 24 Variation of STS with different mixes at different Percentage of Cement

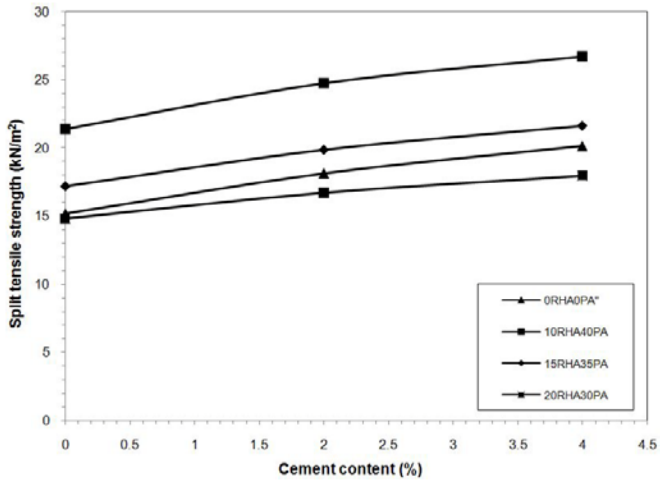

Fig. 25 Variation of STS with cement (%) at different mix combinations

the maximum splitting tensile strengths of 23.6 kPa and 21.8 kPa are observed for mixes 10RHA and 40 PA, respectively. For mixed mode of stabilization, the maximum splitting tensile strength observed is 26.1 kPa**.**

The results of STS tests on RHA and Pond Ash stabilized Clay treated with different percentage of cement are shown in Figs. 24 and 25. It was observed that by addition of 10% RHA and 40% PA, the STS of soil increased. Addition of different percentage of Cement has considerable effects on the STS of the RHA and PA stabilized Clay. With the addition of Cement the STS of soil mix 10RHA40PA goes on increasing and thereafter it decreased as shown in Figs. 24 and 25. The initial increase in the STS with addition of RHA is attributed to the formation of cementitous compounds between the $Ca(OH)_2$ present in the soil and the pozzolana present in the RHA and PA. The decreased in the STS values after addition of 10% RHA and 40% PA may be due to formation of weak bonds between the soil and the cementitous compounds formed (Alhassan 2008).

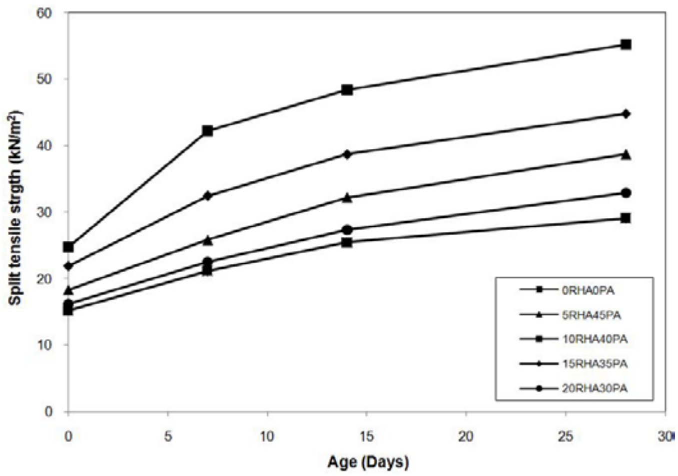

Fig. 26 Variation of STS with curing period at different mix combinations with 2% cement

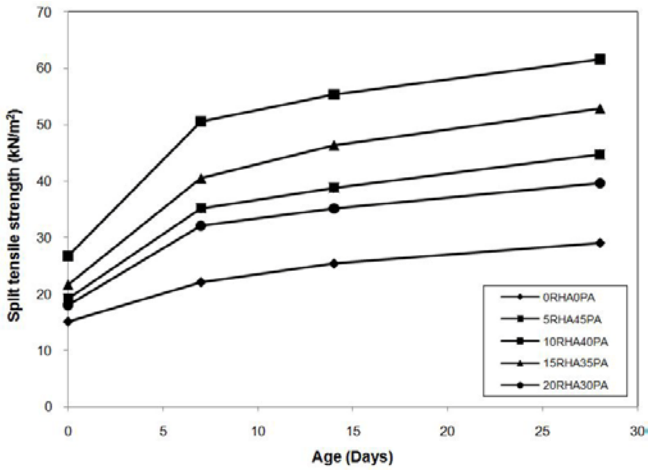

Fig. 27 Variation of STS with curing period at different mix combinations with 4% cement

Table 10 Unconfined compression test and split tensile strength of the soil mixture

Soil mixture	qu (kPa)	Tu (kPa)	$\frac{qu}{Tu}$
Single mode stabilization			
0RHA	110	13.5	0.11
5RHA	142	18.6	0.13
10RHA	160	22.1	0.13
15RHA	154	20.9	0.14
20RHA	130	16.9	0.13
10PA	131	16.6	0.12
20PA	147	17.5	0.12
30PA	158	18.7	0.12
40PA	168	20.8	0.13
50PA	152	18.8	0.12
Combination mode stabilization			
5RHA45PA	161	19	0.11
10RHA40PA	175	25	0.14
15RHA35PA	159	21	0.13
20RHA30PA	145	17	0.12

Fig. 26 show the variation of STS with Curing Period at different Mix Combinations with 2% cement and Fig. 27 shows the variation of the same with 4% cement. The strength of Pond ash, rice husk ash-soil-cement mixtures increases with increasing curing time. In addition, it can be observed that the split tensile strength of pond ash, rice husk ash-soil-cement mixtures after 7, 14, and 28 days of curing period are always higher than those of respective pond ash, rice husk ash-soil samples. The higher strength of RHA, Pond ash, cement stabilized soils compared to natural

Table 11 Values of *qu* and *Tu* with various curing times for selected samples

Soil mixture	*qu* (kPa)				*Tu* (kPa)			
	Age (Days)				Age (Days)			
	0 Days	7 Days	14 Days	28 Days	0 Days	7 Days	14 Days	28 Days
0RHA0PA	110	225	255	282	17.1	22.1	25.4	29.1
5RHA45PA	187	308	345	392	20.9	35.1	38.8	44.7
10RHA40PA	241	408	450	502	26.1	40.4	46.3	52.5
15RHA35PA	221	349	383	437	22.6	50.3	55.2	61.8
20RHA30PA	168	287	324	362	19.9	32.1	35.2	39.6

soil is a result of cementing and pozzolanic properties, respectively (Rahman 1986, Miller and Azad 2000). Based on the STS test, the optimum amount of PA and RHA have been determined as 40%, and 10%, respectively.

Table 10 presents the average unconfined compressive strength and split tensile strength of the specimens with single stabilizer and mixed stabilizer. Table shows that the single stabilizer (RHA and PA) increased both the compressive strength (*qu*) and tensile strength (*Tu*), but the increase in the compressive strength (*qu*) and tensile strength (*Tu*) of mixed stabilizer is higher. The strength ratio, i.e., split tensile strength to unconfined compressive strength (*Tu*/*qu*), is about 0.14 and 0.13 for RHA and PA stabilized soil, which is smaller than the un-stabilized soil.

Table 11 presents the effect of curing on the qu and Tu of the selected samples, showing that the strength increased as the curing period increased. Because of the time-dependent pozzolanic reactions, the stabilization of cement soil is a long-term process (Rao and Rajasekaran 1996). Thus, the strength of the stabilized soil increases and the curing duration increases. In general, the compressive strength increased with time, as did the tensile strength.

5. Conclusions

In this study, different tests like XRD, SEM, Gradation tests, Standard Proctor compaction tests, unconfined compressive strength tests and split tensile strength tests were done to evaluate the behaviour of the soil mixed with the Pond ash and Rice husk ash. The major conclusions drawn are presented below.

- It is found that RHA and PA both have pozzolanic behavior as confirmed from XRD and SEM tests results. So, both can be used as partial replacement material for the cement.
- The maximum percentage of cement used in the study was 4%, which gave sufficient strength. Further increase in cement content may prove to be uneconomical.
- The potential benefit of stabilization is found to depend on the type/amount of stabilizers, stabilizer combinations, and the age. RHA-stabilized soils showed higher strength as compared to their PA counterparts. This can be attributed to the fact that RHA satisfies the requirement for self-cementing characteristics that allows RHA to react with soil in a manner similar to Portland cement. The combination of stabilizers with high PA/RHA also produces better mechanical properties and the user can try various combination schemes to optimize performance.
- Results of particle size distribution have shown that the gradation is improving by the

addition of rice husk ash and pond ash. Cement, pond ash and rice husk ash reduce the plasticity of clayey soil. A considerable reduction of plasticity is attained by cement stabilized soils.

- With increase in the RHA and PA content MDD is decreasing, while OMC is increasing. MDD is decreasing because of the decrease in the specific gravity and OMC is increasing because of the increase in the specific surface area.
- The unconfined compressive strengths of cement-stabilized soils increase with addition of RHA. Addition of RHA needs a lesser amount of cement to achieve a given strength as compared to cement-stabilized soils. Since cement is more costly than RHA this can result in lower construction cost.
- The value of the Strength (UCS and STS) of pure clay is found to be 110 kPa and 16.5 kPa respectively. Subsequently, with the replacement of clay by 4% of cement, there is improvement of 110% and 64% in UCS and STS values respectively with reference to pure clay. Replacement of clay with 10% RHA and 4% cement or 40% PA and 4% cement, there is further improvement (after 28 days of curing) of 209% and 235% in UCS, 155% and 186% in STS respectively with reference to clay only.
- The replacement of clay with of 40% PA, 10% RHA and 4% cement further increased the strength (UCS and STS) of overall mix in comparison to the mixes where PA and RHA were used individually with cement. The improvement (after 28 days of curing) of 336% and 303% in UCS and STS respectively has been achieved in this case with reference to clay only.
- The higher strength of RHA, PA and Cement stabilized soils compared to natural soil is a result of cementing and pozzolanic properties, respectively.
- In general, 4% of cement. 10% RHA and 40% Pond ash shows the optimum amount to improve the properties of soils.
- Pozzolanic activity of stabilizing agents is also confirmed from XRD results.

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