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CEMENT STABILISED AND FIBER REINFORCED CLAY MIXED WITH RICE HUSK ASH

Deepak Gupta*[1], Harpinder Singh[2] & Sanjeev Kumar Sharma[3]
[*1]Former Research Scholar, Department of Civil Engineering, National Institute of Technology, Jalandhar, India,
[2] Research Scholar, Department of Industrial and Production Engineering, National Institute of Technology, Jalandhar, India
[3]Former Research Scholar, Department of Electronics and Communication Engineering, National Institute of Technology, Jalandhar, India

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ABSTRACT

A series of tests were conducted to study the combined effect of polypropylene fiber, cement and rice husk ash on kaolin clay. Cement and rice husk ash were added to clayey soil at ranges of 0–6% and 0–20%, respectively. Fiber content was varied as 0, 0.5, 1, 1.5, and 2%. To understand the impact of these additives on clay different tests like; compaction tests, unconfined compression tests (UCS), split tensile strength tests (STS) and California bearing ratio tests (CBR). In addition SEM (scanning electron microscopy), TEM (transmission electron microscopy) and XRD tests were carried out on certain samples in order to study the surface morphological characteristics, particle size 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 tests and for CBR tests sample were soaked for 4 days. Based on optimum values obtained for cement and rice husk ash, tests were conducted on test specimens prepared from rice husk ash-clayey soil- cement-fiber mixture after 28 days of curing. Based on the favourable results obtained, it can be concluded that the expansive soil can be successfully stabilized by the combined action of fibers, cement, and rice husk ash.

KEYWORDS: Rice Husk Ash; OMC; MDD; Cement; Stabilization.

I. INTRODUCTION

Weak or soft soils are undesirable in case of structure which transfer high load to the ground like multi-storey buildings, embankments with heavy traffic etc. These soils are susceptible to large settlements due to its poor shear strength and high compressibility. Different ground improvement techniques like densification techniques, reinforcement techniques and stabilization techniques are available options for improvement of the properties of weak soil.

Among these technique addition of different materials like cement, fiber, and wastes like; fly ash, rice husk ash etc. is one of the popular technique among the engineers.

Utilization of binder materials like cement and lime is very useful to improve the strength characteristics of soil. During shearing particles of soil moves relative to each other, this is the cause for the settlement and failure in the soil. Cement binds clay particle through its cementitious property. Many researchers have shown that performance of cement or lime increases in presence of pozzolanic materials like fly ash, pond ash etc (Beeghly 2003, Kumar and Deepak 2016).

Use of fiber reinforcement is old techniques used from very long time. Mechanism of fiber reinforcement is similar to the plant root reinforcement. Different researchers have performed

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triaxial tests, unconfined compression tests, CBR tests, direct shear tests, and tensile and flexural strength tests to understand the effect on the soil (Freitag 1986; Setty and Rao 1987; Maher and Gray 1990; Al-Refeai 1991; Fatani et al. 1991; Maher and Ho 1994; Ranjan et al. 1996; Nataraj and MacManis 1997; Consoli et al. 1998, 2002, 2005; Santoni et al. 2001; Kumar et al. 2005; casagrande et al 2006, 2007, 2007; Kim et al 2008; Park sung-sik 2008; Bera et al. 2009; Fatahi B 2012; Divya et al 2014; Li et al. 2014; Anggraini et al. 2014; Botero et al. 2015). One of the primary advantages of randomly distributed fibers is the absence of potential planes of weakness that can develop parallel to oriented reinforcement (Maher and Gray 1990). Performance of the fiber depends upon the properties of soil like; density of soil, types of soil, gradation etc. and on the fiber properties like; fiber content, length of fiber, types of fiber etc. (Priyadarshee et al. 2014)

Rice husks are produced during the operation of paddy, which varies from 20% (Mehta, 1986) to 23% (Della et al., 2002) by weight of the paddy. The rice husk is a waste material used in the boiler for processing paddy. This process generates ash about 20% of its weight as ash (Mehta, 1986). The ash produced is known as rice husk ash. Its properties depends upon the the burning process (Nair et al., 2006). Rice husk ash is utilized as pozzolanic material (ASTM C 168, ASTM 1997) due to its high amorphous silica content (Mehta, 1986). Production of paddy in India is about 100 million tonnes, which can produce more than 4 million tonnes of RHA (Ramakrishna and Kumar, 2008). Different researchers like Brooks 2009, Alhassan 2008, Noor et al. 1990, Haji ali et al. 1992 etc. have shown that rice husk ash can improve the geotechnical properties of soil. Rice husk ash alone doesn't show cementitious property (Haji 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; Haji Ali et al., 1992; Rama Krishna and Kumar, 2006; Basha et al., 2005; Chandra et al., 2005; Sharma et al., 2008)

Most of the studies are done on clay mixed with rice husk and cement or with fiber alone. The objectives of this paper are to study the effects of fiber inclusions on the lime treated clay mixed with rice husk.

Scope of present study
The geotechnical characteristics of cement treated kaolin clay mixed with fiber and rice husk ash were investigated. Cement was added to clayey soil at 0–6% and rice husk ash was added to the clayey soil at 0–20% by dry weight of sample. Test specimens were subjected to compaction tests, unconfined compression tests (UCS), split tensile strength tests (STS) and California bearing ratio (CBR) tests. Specimens were cured for 7, 14, and 28 days after which they were tested for unconfined compression tests and split tensile tests. Test with fiber was performed on the sample with curing period of 28 days. Samples were tested with 0, 0.5, 1.0, 1.5, and 2% polypropylene fibres (3, 6, 12 mm lengths). This paper presents the details and results of the experimental study and the conclusions from the study. Materials used in study was also used in other studies (Kumar and Gupta 2015, Gupta and Kumar 2017(a, b))

II. EXPERIMENTAL INVESTIGATION

Material

Soil
Kaolin clay was used in this study which was obtained from the locally available market. The soil was firstly air dried and then basic and index properties of soil were found. According to Unified Soil Classification System (USCS) soil is classified as CL (clay with low plasticity). Properties of the soil are presented in Table 1. From the particle size analysis, it was found that 100% of soil lies under fined grained soil.

Table 1.*Properties of Clay*

PROPERTIES	VALUES
Specific gravity (G)	2.65
Liquid limit (%)	43.3
Plastic limit (%)	19.5
Plasticity index (I_p)	23.8
Optimum moisture content (%)	16.5
Maximum dry density	1.75gm/cc

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Rice Husk Ash

Rice husk ash used in this study was obtained from the locally available market. It's chemical and physical properties are shown in the Table 2. However the chemical characteristic of the aforementioned rice husk ash shows that SiO_2 is major constituent. Presence of silica is the reason for the pozzolanic behaviour of rice husk ash.

Table 2.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

Ordinary Portland Cement (Opc-43 Grade)

The physical properties of cement are shown in Table 3. For this study the Ordinary Portland cement of SHREE ULTRA TECH Cement Company was used, which was available in local market.

Table 3.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

Fibers

Polypropylene fibers were used in this study. Fibers used in the experiment were purchased from the Nina Concrete Systems Pvt. Ltd. The length of the polypropylene fibres used in present study is varied as 3, 6 mm and 12 mm. Fibers are of fibrillated type. Properties of the fiber used in this study are presented in Table 4.

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Table.4. Physical and mechanical properties of fibers

Property	Value
Specific gravity	0.9-0.91
Cut length (L)	3 mm, 6 mm, 12mm
Diameter (D)	0.02 mm
Aspect Ratio (L/D)	150, 300, 600
Water Absorption (24 hours duration)	0.3%
Colour	White
pH value	Not applicable
Melting point	165° c
Solubility in water	Below 0.1%
Acid resistance	Excellent
Alkali resistance	Excellent

III. EXPERIMENTAL DETAILS

Planning of Experiments

A series of tests were conducted on the cement treated Kaolin clay mixed with various percentages of rice husk ash and fiber. The tests performed include XRD, SEM, modified proctor compaction test, unconfined compressive strength test, split tensile strength test and California bearing ratio tests. Six different combination of the mix were used in this study. Details of the combination are presented in Table 6. In all combination additives were used as replacement of clay. In combination 1 tests were conducted on the clay mixed with the cement alone. Content of the cement (W_c) was varied as 0%, 2%, 4% and 6%. In combination 2 test was conducted on the clay mixed with rice husk ash and content of rice husk ash (W_R) was varied as 0%, 5%, 10%, 15% and 20%. Combination 3

Table 5 Detail of combination

$W=W_R+W_S+W_C+W_f$	Variation of W_R (% by total dry weight)	Variation of W_S (% by total dry weight)	Variation of W_c (% by total dry weight)	Variation of W_f (% by total dry weight)
Combination 1	0	100, 98, 96, 94	0, 2 ,4, 6	0
Combination 2	0, 5, 10, 15, 20	100, 95, 90, 85, 80	0	0
Combination 3	0, 5, 10, 15, 20	100, 95, 90, 85, 80	2	0
Combination 4	0, 5, 10, 15, 20	100, 95, 90, 85, 80	4	0
Combination 5	0, 5, 10, 15, 20	100, 95, 90, 85, 80	6	0
Combination 6	10	100, 95, 90, 85, 80	6	0.5, 1, 1.5, 2

Specimen Preparation and Testing Procedures: Overview

Soil specimens for different combination were prepared according to the content of the additives. An amount of soil was mixed with 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 the total dry weight W of a rice husk ash-soil-cement-fiber mixture is

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$$W= W_s + W_P + W_R + W_C \ldots\ldots \text{(Eq.1)}$$

Where W_R, Ws, Wc, and Wf = weights of rice husk ash, soil, cement, and fibers, respectively.

Specimen Preparation and Testing Procedures

Unconfined Compressive strength and Split-Tensile strength Tests

The unconfined compressive strength (UCS) test apparatus was employed in the tests. Samples were shaped in a mould with a length of 76.2 mm and an inner diameter of 38.1 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 D5102-09 (ASTM 2009b) and ASTM C496-11 (ASTM 2011b), 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

$$\text{Split tensile strength} = \frac{2Pmax}{\pi.L.D}$$

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

Specimen Preparation and Testing Procedures:

California Bearing Ratio Test

The California bearing ratio tests were conducted on specimens prepared in a cylindrical mould of 150 mm-diameter and 175-mm height. The specimens were prepared by compacting samples in five layers at its MDD and OMC based on the modified Proctor compaction test. The tests were conducted in accordance with ASTM D1883-07 (ASTM 2007). The specimens were immersed in water for 3 days before crushing by applying compressive pressures. This condition produced a soaked CBR value.

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.

TEM analysis of RHA

The transmission electron microscopy analysis was carried out using TEM AMT Camera System at HV 100 kV and direct magnification of 600 k×. The diluted solution of RHA sample was prepared using ultra sonication approach. Finally, a very small portion of diluted sample was observed under microscope.

IV. RESULTS AND DISCUSSION

Influence of rice husk ash, cement, and randomly distributed` fibers on the geotechnical characteristics of clayey soil was investigated by conducting modified proctor compaction tests, unconfined compression tests, split tensile strength tests and California bearing ratio tests. 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 Results obtained from these tests are presented in the following sections.

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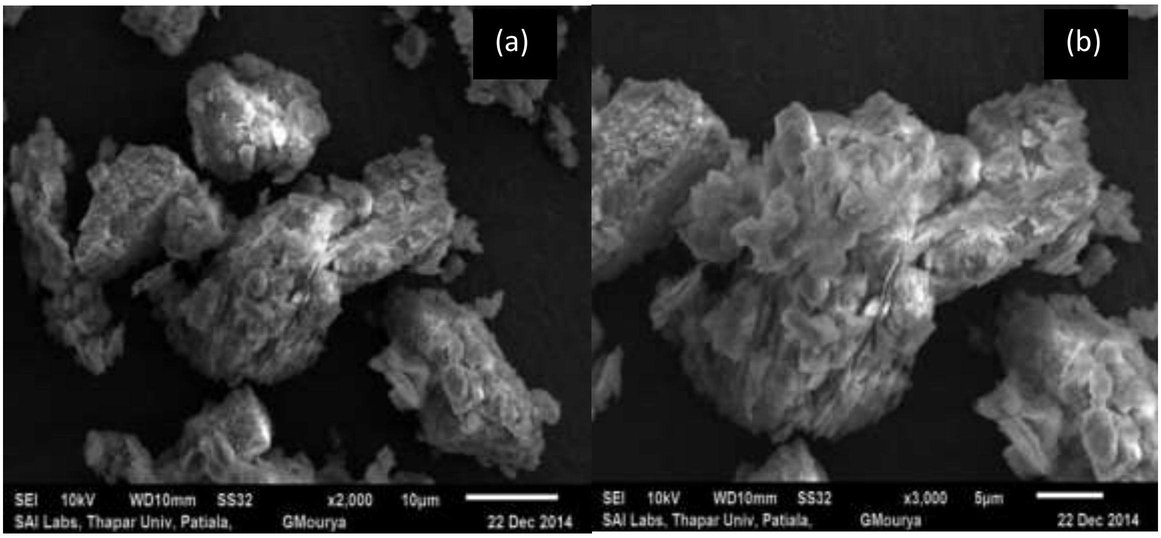
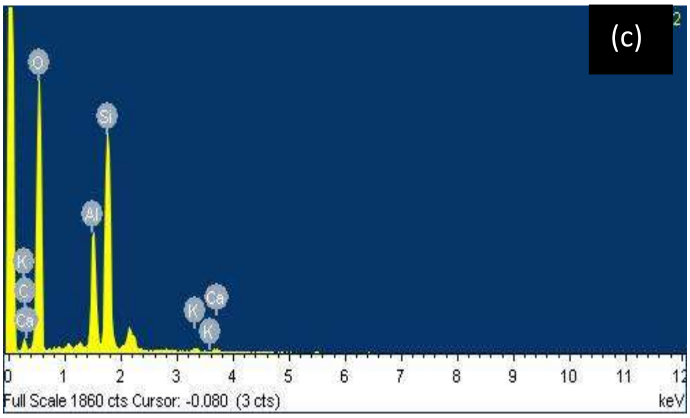
Surface Morphological Characteristics

Fig. 1(a) show the SEM images of Soil + RHA mixture after 7 days, indicating the platy nature of Kaolin clay particles. The additional particles of RHA with irregular surface morphology can also be observed. Fig. 1(b) shows the magnified view of soil + RHA. Fig 1(c) and fig 1(d) respectively presents the EDS spectrum and elemental composition of soil +RHA.

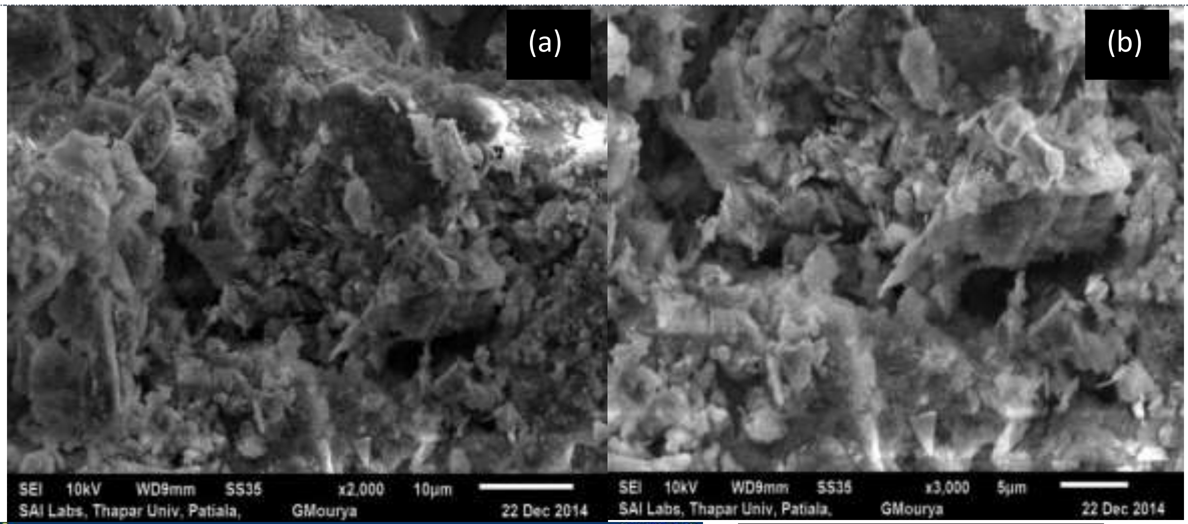


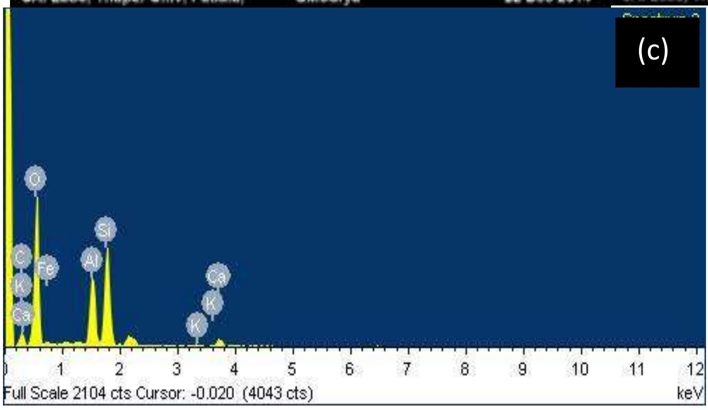


Element	Percentage
C	4.41
O	66.97
Al	9.03
Si	18.76
Ca	0.37
K	0.46

Fig. 1: 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

Fig. 2(a) show the SEM images of Soil + RHA + Cement mixture after 7 days, indicating the formation of Calcium-Silicate-Hydrate (C-S-H) gel in good amount. This growth of CSH gel is a result of sufficient stabilizing activity due to combined effect of RHA and cement together as stabilizers. Fig. 2(b) is the magnified view of Fig. 2(a), revealing the exact surface morphology of CSH gel formed as a consequence of pozzolanic reaction. Fig 2(c) shows the EDS spectrum of the mixture after 7 days of curing. The elemental composition supports the fact that presence of cement as an additional stabilizer causes relative increase in percentage of Calcium, confirming higher formation of CSH gel.





Element	Percentage
C	9.04
O	66.07
Al	8.59
Si	14.09
K	0.27
Ca	1.45
Fe	0.49

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

XRD Results of the specimens

As observed from the X- Ray Diffraction patterns of the untreated clay (A) and treated clay samples in Fig. 3, it was noticed 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 2θ=24.8°, 26.6° and 60.5° (d=3.58 Å, 3.34 Å and 1.52 Å respectively); and characteristic diffraction peaks corresponding to the presence of Quartz (SiO_2), at 2θ=20.8° and 50.1° (d=4.25 Å and 1.8 Å) (Basha et al 2005, Pranshoo and Musharraf 2012). Both kaolinite and quartz are present in high amount which is indicated from sharp intensity peaks corresponding to them in XRD pattern. The stabilizing actions of RHA individually and RHA and cement both are indicated by the disappearance of peaks corresponding to Kaolinite and Quartz in XRD patterns B and C. However, the pozzolanic action is more in case of RHA and Cement as combined mode of stabilization as observed from high intensities of pozzolanic product $CaCO_3$ and reduced intensities of Quartz peaks. This could be attributed to the cementitious pozzolanic reactions taking place between the stabilizing additive (stabilizing material) and the basic clay minerals. Moreover, XRD patterns of all the stabilized specimens revealed additional peaks of Calcite ($CaCO_3$); peak positions at 2θ=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 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.

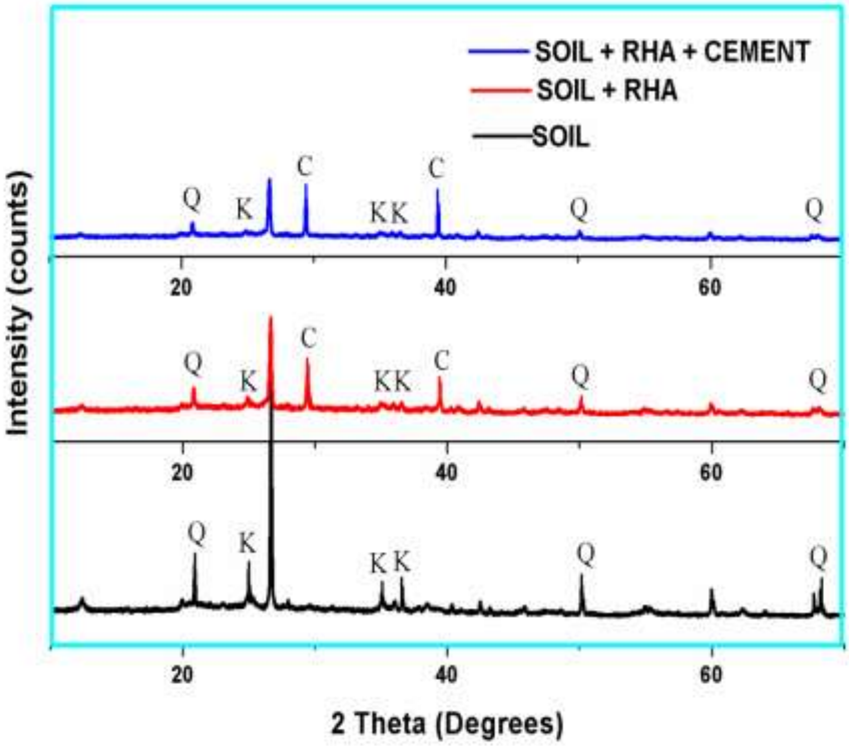


Fig 2.XRD Patterns of clay treated with rice husk ash

TEM results

The TEM observation of RHA indicates that the average particle size is around 35 nm. This can be seen in Fig. 4a. In addition, the surface of RHA particles is porous and the presence of pores can be seen in Fig.4b. This observation is evidence that RHA particles have a tendency to absorb water, consequently showing higher values of optimum moisture content.

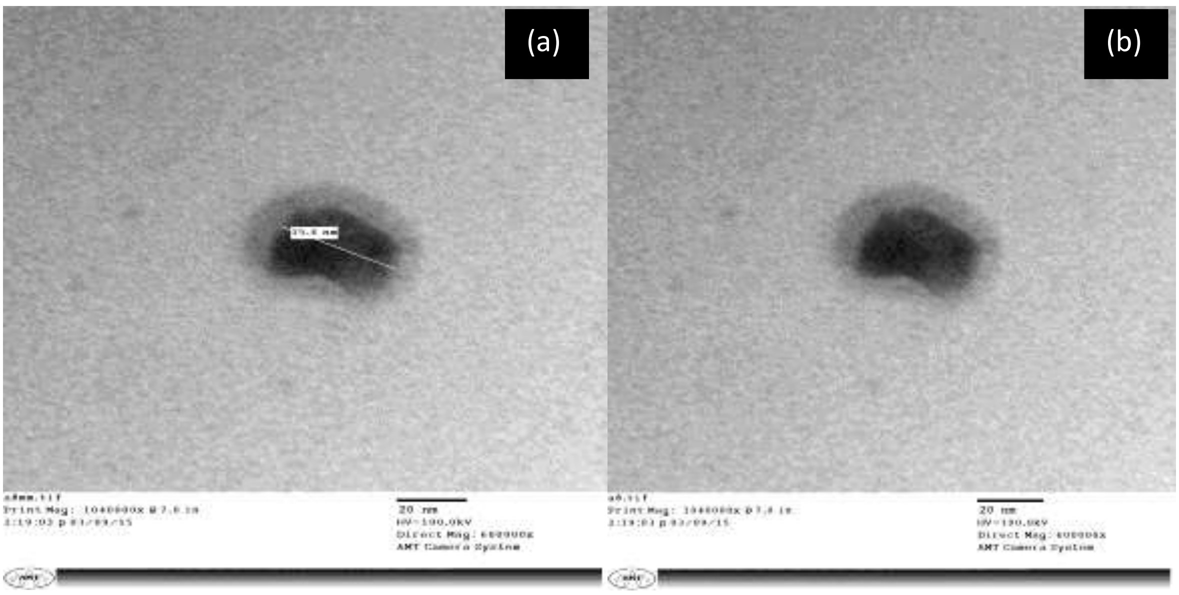


Fig.4: TEM images of RHA showing (a) Average Particle Size (b) Porous surface of particles

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Compaction Test

The tests were performed as per ASTM D698 (2000) specifications for modified Proctor compaction tests. Modified proctor compaction test were carried out on the rice husk ash-soil-cement-fiber mixture proportions. The dry weight of total mixture (*W*) was taken as per Eq. (1). The compaction tests were performed for various combinations of rice husk ash-soil-cement-fiber mixtures as detailed in Table 5. Fig 5 and Fig 6 shows the variation of maximum dry density and optimum moisture content for different proportions of rice husk ash-soil-cement mixtures. From the results, it is 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 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 addition of rice husk ash, there is further decrease in maximum dry density and increase in optimum moisture content. The presence of rice husk ash 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). The increase in OMC is probably a due to the reasons that exceeding water absorption by RHA as a result of its porous properties, as reported in Zhang et al. 1996

The results of compaction tests showed that fibers had no significant effect on maximum dry density and optimum moisture content of rice husk ash-soil-cement-fiber mixtures. This is somewhat different from the trend observed by Setty and Rao (1987) that both maximum dry density and optimum moisture content increase with increase in fiber content in silty sand mixed with polypropylene fibers.

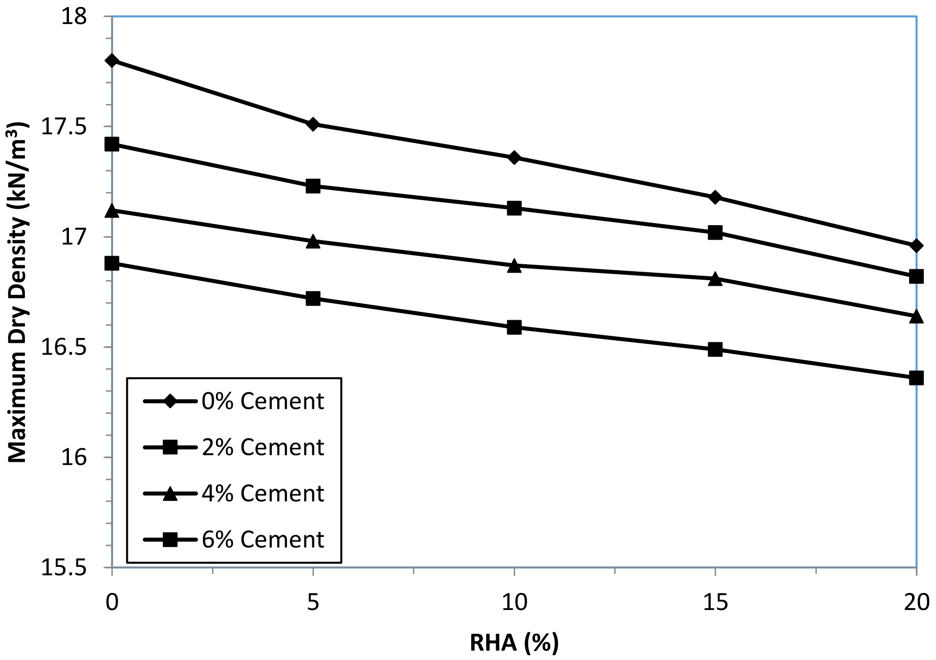

Fig.5. Dry density versus RHA (%) with different % of cement

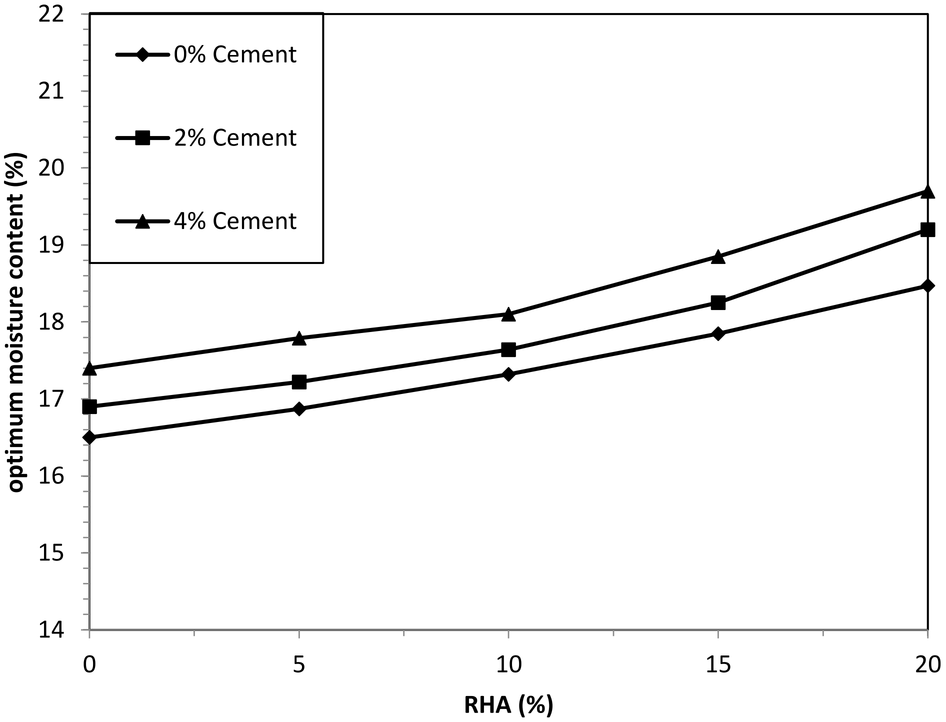

Fig.6.Optimum moisture content (%) versus RHA (%) at different (%) of cement

Unconfined compressive strength tests (UCS)

Fig 7 and 8 shows the effects of RHA on UCS clay specimens for varying cement contents. The unconfined compressive strength increased with increasing cement content for given RHA content. For example, the UCS was 160, 175, 189 and 205 kPa, respectively, when the cement content was 0, 2, 4, and 6% for a RHA content of 10%. The UCS increased by 28% when the cement content was increased from 0 to 6% at a RHA content of 10%. This indicates that 6% was the optimum content for cement in RHA-blended clays also. For given cement content, UCS increased with increasing RHA content. However, a RHA content of 10% gave the maximum value of UCS for all cement contents. Unconfined compressive strength decreased when RHA content was increased to 15% irrespective of cement content, thus, indicating that 10% was the optimum RHA content for clay-cement blends. The initial increase in the UCS with addition of RHA is attributed to the formation of cementitious compounds between the $Ca(OH)_2$ present in the clay and the pozzolana present in the rice husk ash. The decrease in the UCS values after addition of 10% rice husk ash 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 a., 1992; Muntohar, 2005; Jha and Gill, 2006; Alhassan, 2008).

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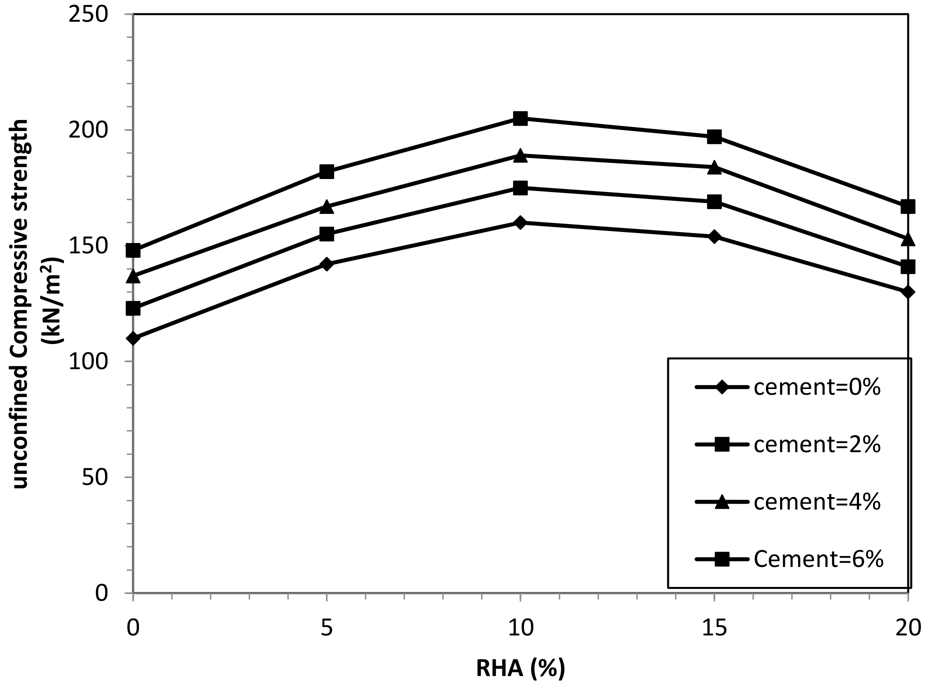

Fig.7. Variation of unconfined compressive strength with percentage of rice husk ash for different percentage of cement (0 days curing)

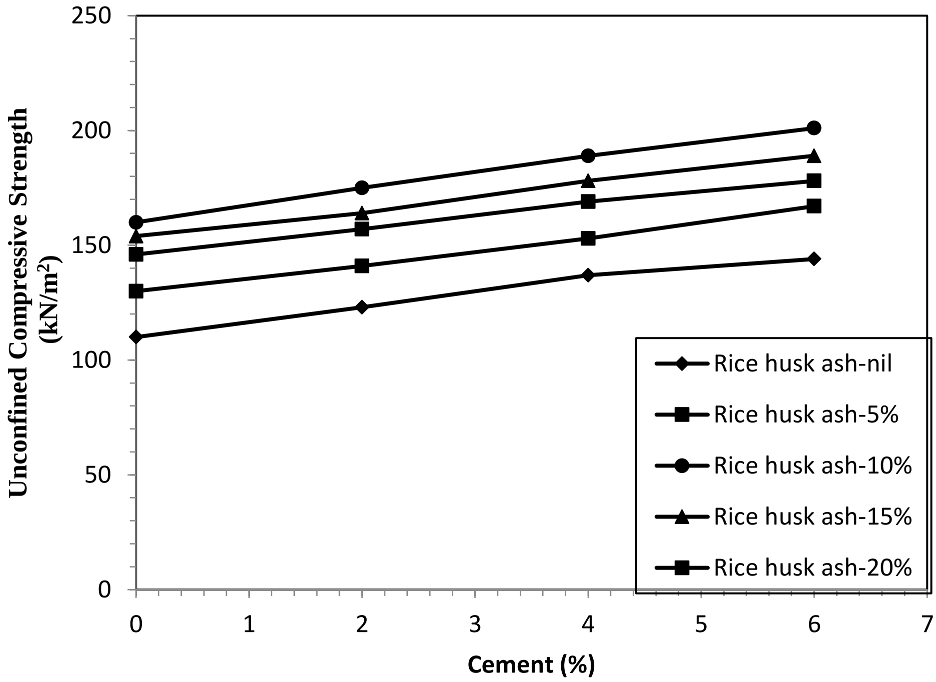

Fig.8. Variation of unconfined compressive strength with percentage of cement for different percentage of rice husk ash (0 days curing)

Fig 9-11 present the effect of curing on the unconfined compressive strength of the samples, showing that the strength increased as the curing period increased. Because of the time-dependent pozzolanic reactions, the stabilization of lime soil is a long-term process (Rao and Rajasekaran 1996). The strength of rice husk ash-soil-cement blend increases with increasing curing period. In addition, it can be observed that the unconfined compressive strengths of rice husk ash-soil-cement blend after 7, 14, and 28 days of curing period are always higher than those of respective rice husk ash- soil samples. The higher strength of rice husk ash, cement

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stabilized soils compared to natural soil is a result of chemical reactions such as cation exchange, pozzolanic reaction, carbonation, and cementation due to the pozzolanic reaction, flocculation of clay particles taking place, resulting in agglomeration into large sized particles, which resist the applied compressive load more effectively than those of untreated clay. The role of cementation is to produce cementitious materials, which also help in resisting the load better (sharma 2008, Rahman 1987; Miller and Azad 2000). The optimum value of rice husk ash and cement may be adopted as 10 and 6%, respectively, as is clear from Figs. 9–11.

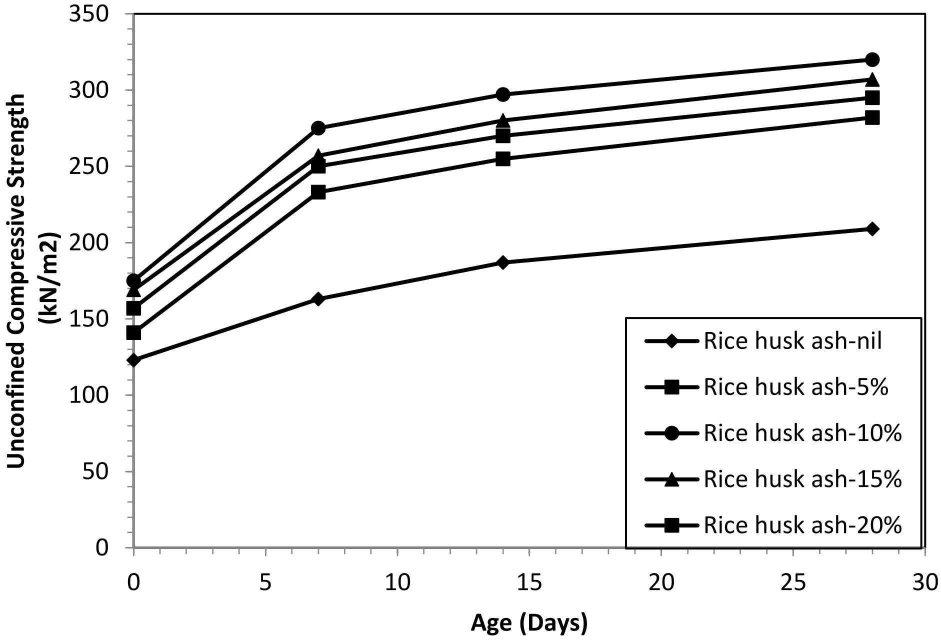


Fig.9. Variation of unconfined compression strength with ages (days) for different percentage of rice husk ash with 2% Cement.

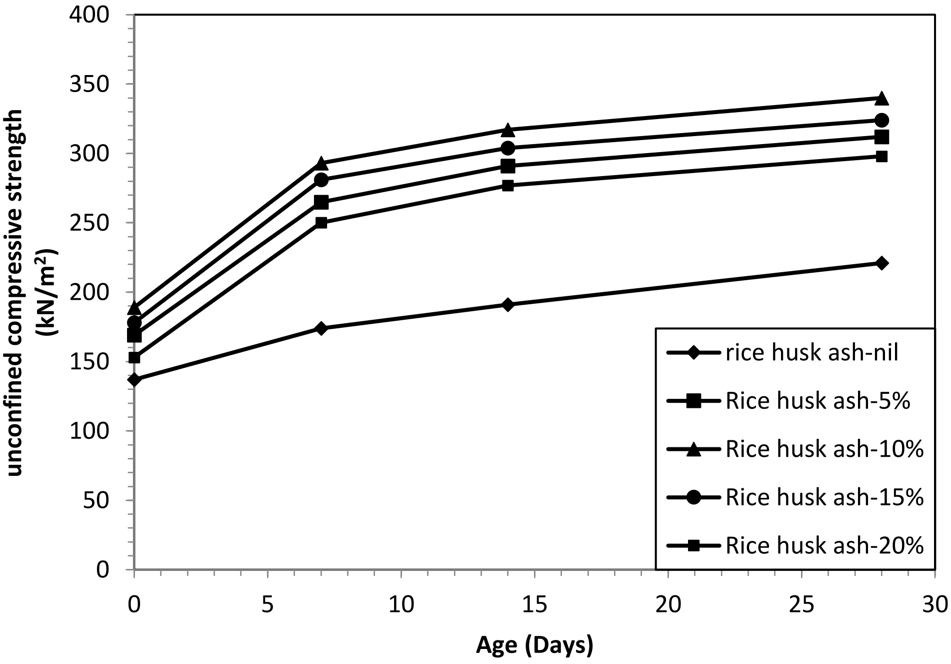


Fig.10. Variation of unconfined compressive strength with age (days) for different percentage of rice husk ash with 4% Cement

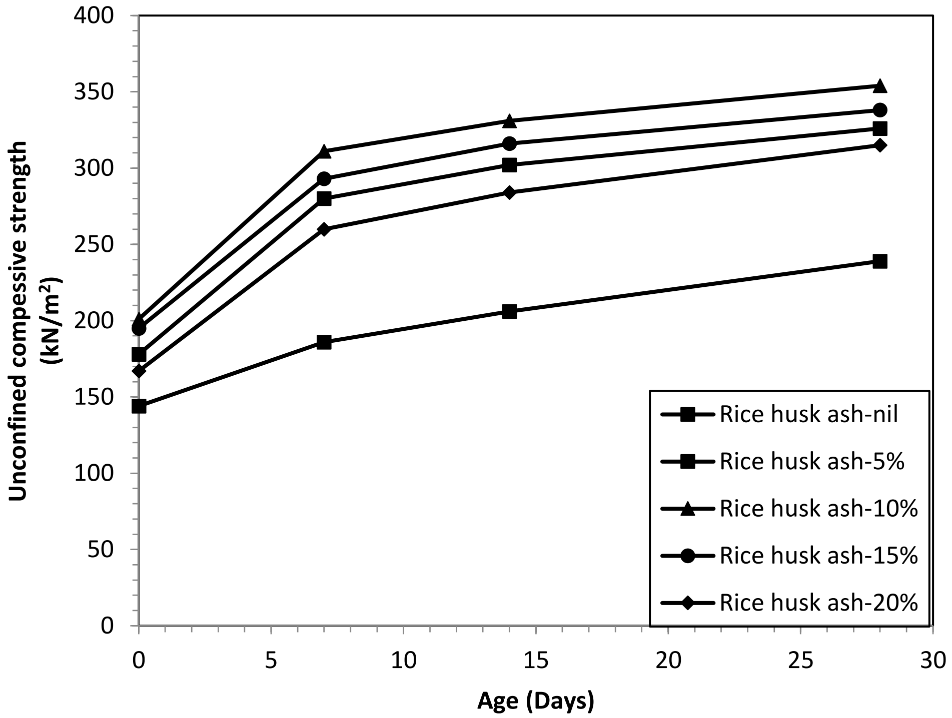
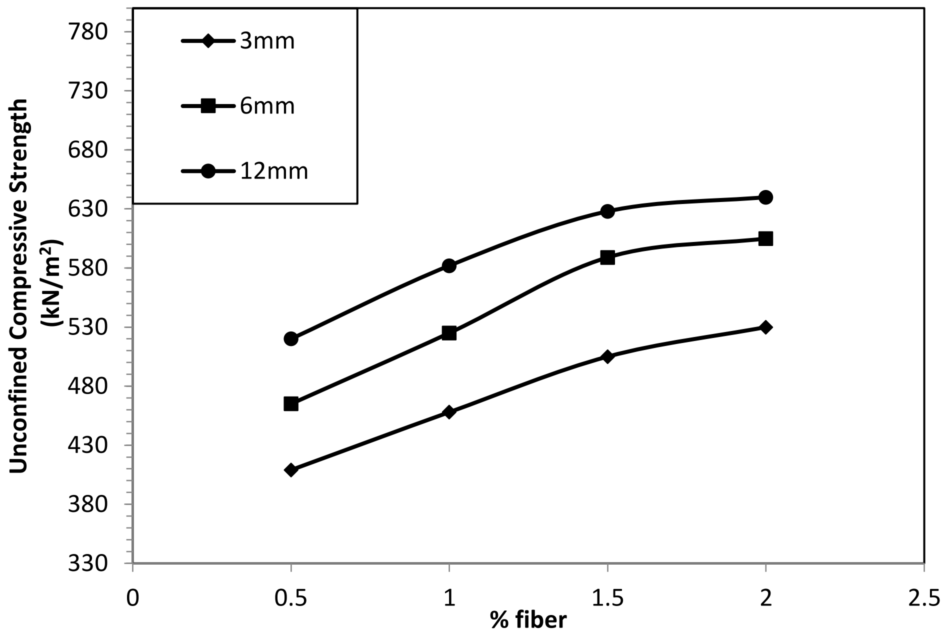


Fig.11. Variation of unconfined compression strength with ages (days) for different percentage of rice husk ash with 6% Cement.

Based on the previous discussion, the fiber-reinforced specimens were tested for 10% rice husk ash and 6% cement in the rice husk ash-soil-cement-fiber blend. Polypropylene fibers of length 3 mm, 6 mm, and 12 mm plain were mixed in different proportions of 0.5, 1.0, 1.5, and 2.0%. Specimens prepared for rice husk ash-soil-cement-fiber mixtures (as per Combination 6 shown in Table 5) were tested for each fiber length after 28 days of curing. At the end of curing period the specimens were soaked in water for a period of 24 h before testing. The results of unconfined compressive strength are presented in Fig. 12. The curves show that the addition of 2% of 3 mm fibers or 1.0% of 6 mm fibers increases unconfined compressive strength by approximately 56% as compared to that of same mixture without fibers. Also, with the addition of 1.5% of 6 mm fibers or 1% of 12 mm fibers, the gain in unconfined compressive strength is about 66% in comparison to that of the same mixture without fibers.



Split Tensile strength tests (STS)

Fig 13 and 14 shows the effects of RHA on STS of clay specimens for varying cement contents. The split tensile strength increased with increasing cement content for given RHA content. For example, the STS were 21, 23, 24 and 25 kPa, respectively, when the cement content was 0, 2, 4, and 6% for a RHA content of 10%. The STS increases with the increase in the cement content from 0 to 6% at a RHA content of 10%. This indicates that 6% was the optimum content for cement in RHA-blended clays also. For given cement content, STS increased with increasing RHA content. However, a RHA content of 10% gave the maximum value of STS for all cement contents. Split tensile strength decreased when RHA content was increased to 15% irrespective of cement content, thus, indicating that 10% was the optimum RHA content for clay-cement blends. The initial increase in the STS with addition of RHA is attributed to the formation of cementitious compounds between the $Ca(OH)_2$ present in the clay and the pozzolana present in the rice husk ash. The decrease in the STS values after addition of 10% rice husk ash 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 a., 1992; Muntohar, 2005; Jha and Gill, 2006; Alhassan, 2008).

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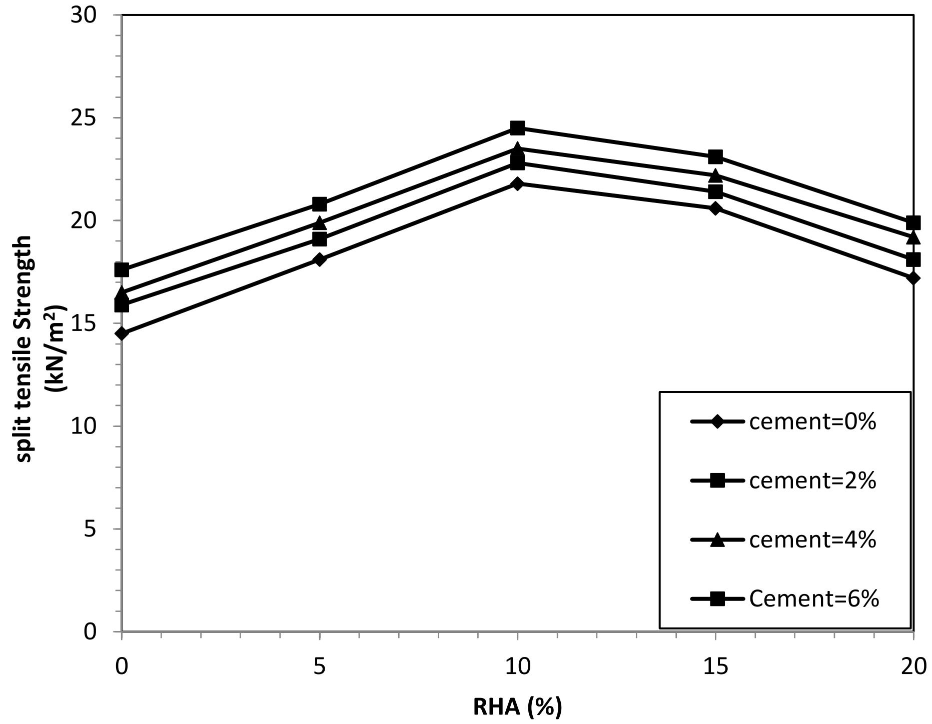

Fig.13. Variation of split tensile strength with percentage of rice husk ash for different percentage of cement (0 days curing)

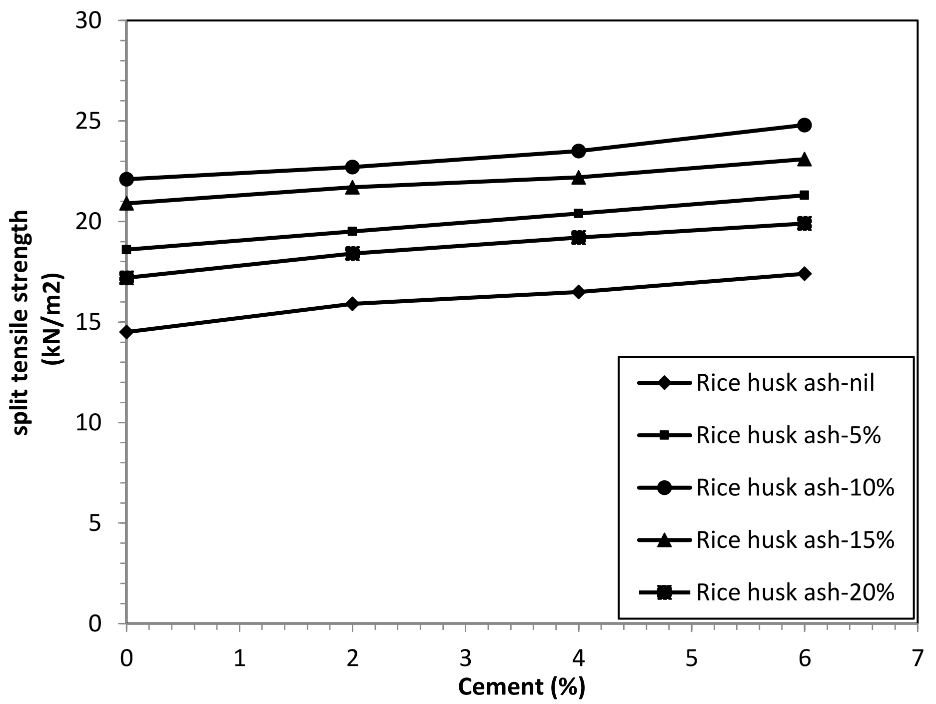

Fig.14. Variation of split tensile strength with percentage of cement for different percentage of rice husk ash (0 days curing)

Fig 15-17 presents the effect of curing on the split tensile strength of the samples, showing that the strength increased as the curing period increased. In addition, it can be observed that the unconfined compressive strengths of rice husk ash-soil-cement blend after 7, 14, and 28 days of curing period are always higher than

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those of respective rice husk ash- soil samples. The higher strength of rice husk ash, cement stabilized soils compared to natural soil is a result of chemical reactions such as cation exchange, pozzolanic reaction, carbonation, and cementation due to the pozzolanic reaction, flocculation of clay particles taking place, resulting in agglomeration into large sized particles, which resist the applied compressive load more effectively than those of untreated clay. The role of cementation is to produce cementitious materials, which also help in resisting the load better (sharma 2008, Rahman 1987; Miller and Azad 2000). The optimum value of rice husk ash and cement may be adopted as 10 and 6%, respectively, as is clear from Figs. 7–9.

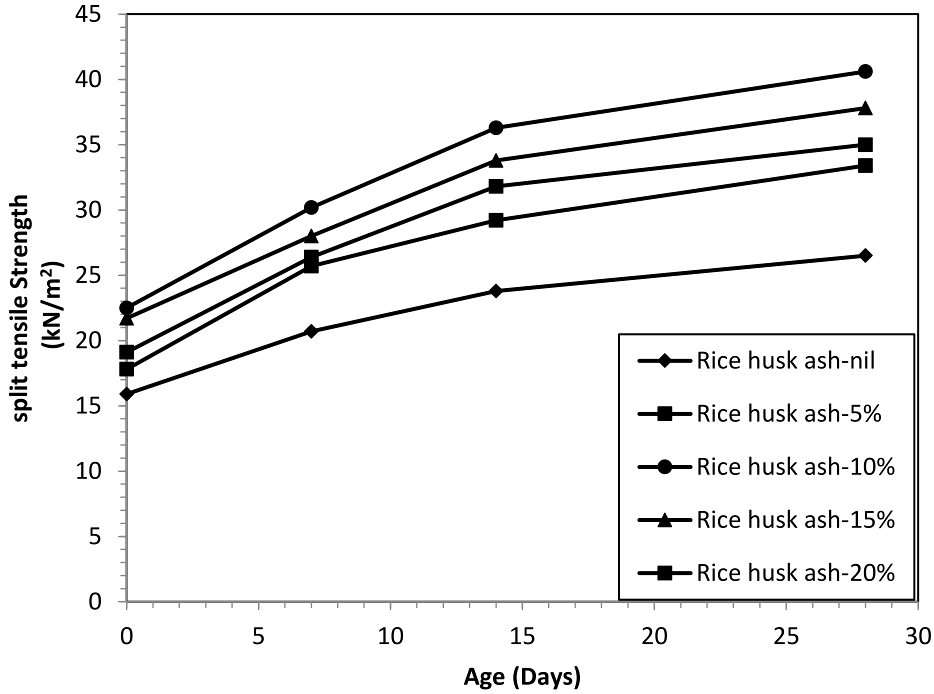

Fig.15. Variation of split tensile strength with age (days) for different percentage of rice husk ash with 2% Cement

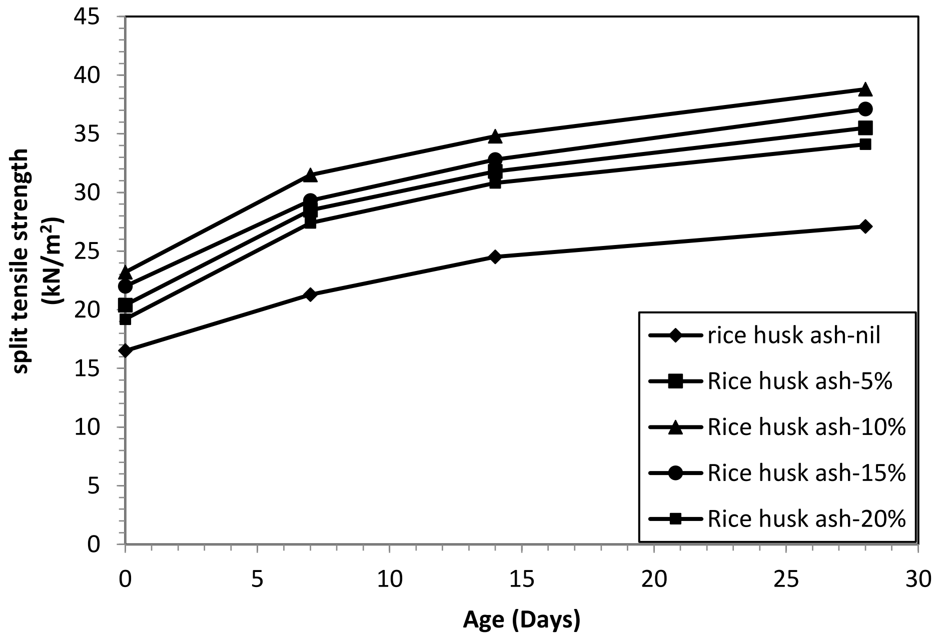

Fig.16. Variation of split tensile strength with age (days) for different percentage of rice husk ash with 4% Cement

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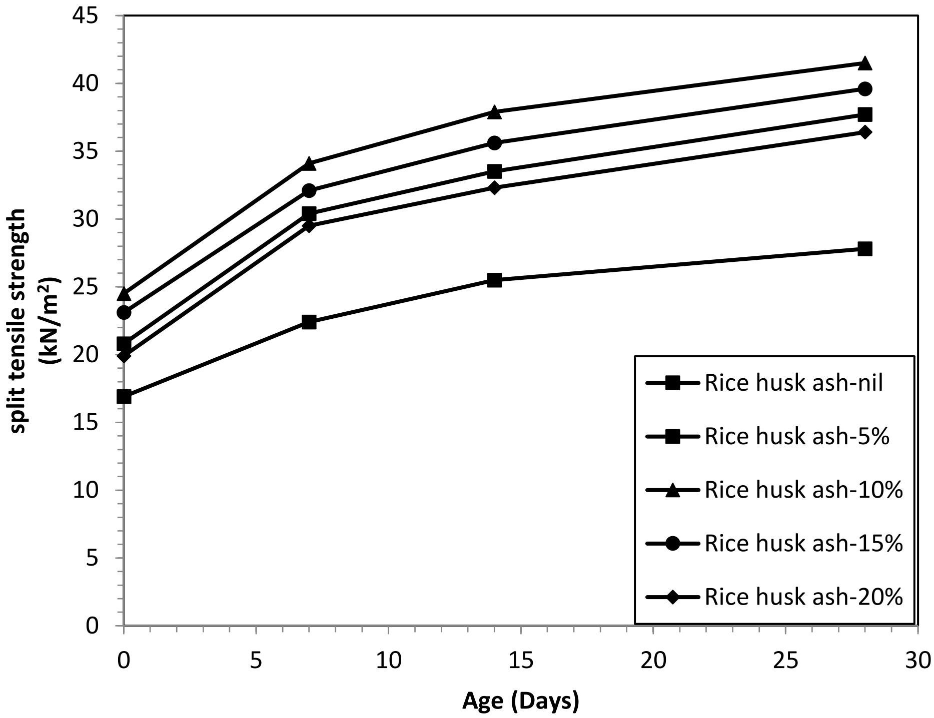

Fig.17: Variation of split tensile strength with age (days) for different percentage of rice husk ash with 6% Cement.

Based on the previous discussion, the fiber-reinforced specimens were tested for 10% rice husk ash and 6% cement in the rice husk ash-soil-cement-fiber blend. Polypropylene fibers of length 3 mm, 6 mm, and 12 mm plain were mixed in different proportions of 0.5, 1.0, 1.5, and 2.0%. Specimens prepared for rice husk ash-soil-cement-fiber mixtures (as per Combination 6 shown in Table 5) were tested for each fiber length after 28 days of curing. At the end of curing period the specimens were soaked in water for a period of 24 h before testing. The results of split tensile strength are presented in Fig. 18. The curves show that the addition of 2% of 3 mm fibers or 1.0% of 6 mm fibers increases split tensile strength by approximately 49% as compared to that of same mixture without fibers. Also, with the addition of 1.5% of 6 mm fibers or 1% of 12 mm fibers, the gain in split tensile strength is about 65% in comparison to that of the same mixture without fibers.

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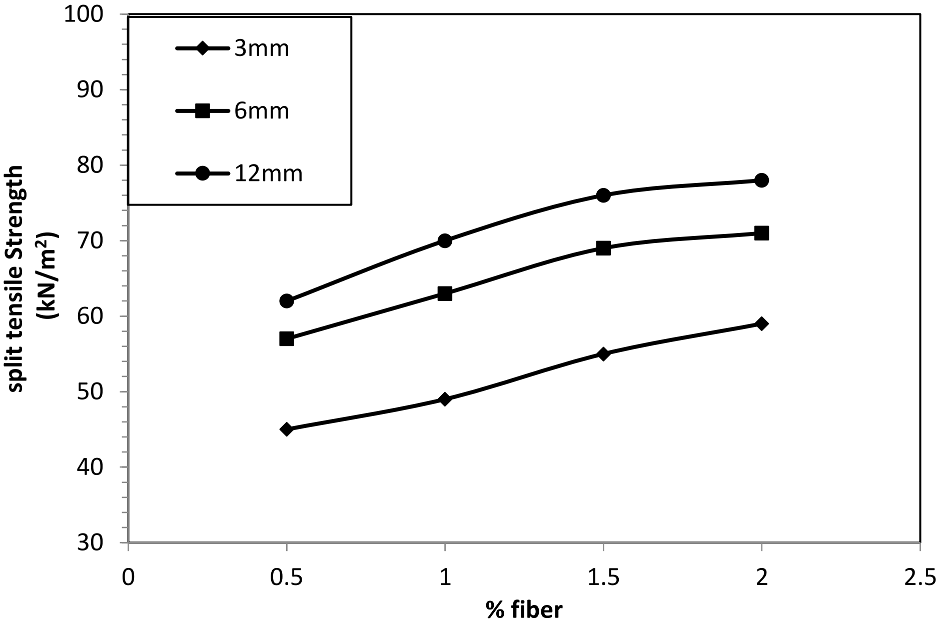

Fig.18.Variation of split-tensile strength with % of fibers, for soil mixed with 6% of cement and 10% rice husk ash

California bearing ratio

The CBR value of the subgrade is an important factor for the designing pavement thickness composition. The CBR value is commonly used to evaluate the quality of road materials. Fig. 19 shows the 3-day CBR values for un-stabilized and stabilized soil mixtures. The un-stabilized soil had the smallest CBR value at 2.5%, when subjected to 3 days of water immersion. The Cement/RHA mixture enhanced the bearing of soil in which the soaked CBR increased from 2% to 30% with the addition of 10% RHA and 6% cement. The reason for the CBR improvement was because of the cementing pozzolanic reaction between the soil and Cement/RHA material (Brooks 2009). The chemical hydration during the reaction, regarded as the primary reaction, formed additional cementitious material that bound particles together and enhanced the strength of the soil.

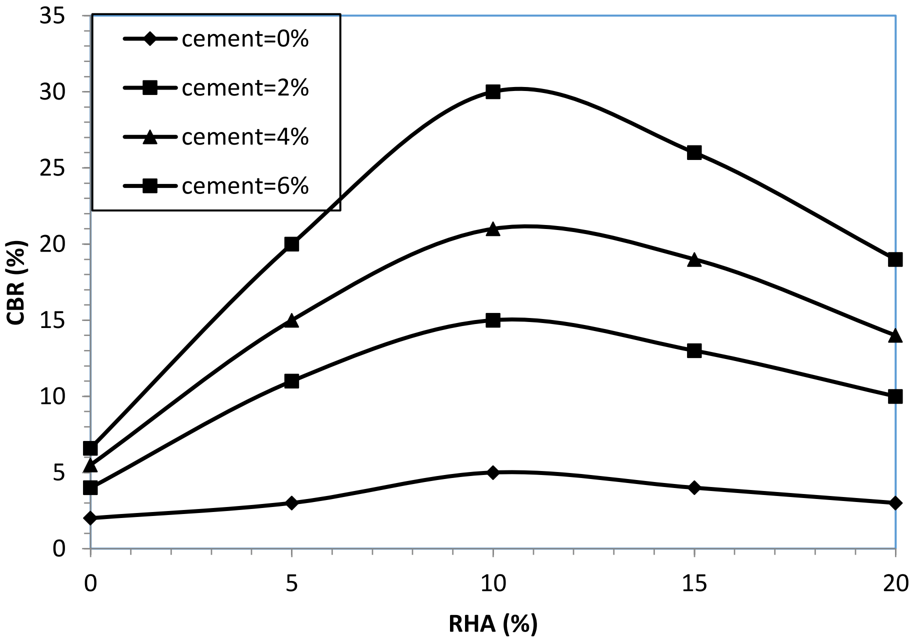

Fig.19. Variation of California bearing ratio with rice husk ash content

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Based on the previous discussion, the fiber reinforced specimens were tested for 10% RHA and 6% cement in the RHA-clay-cement-fiber mixtures. Polypropylene fiber of length 3 mm, 6 mm and 12 mm were mixed in different proportions of 0.5, 1, 1.5 and 2%. Specimens prepared for rice husk ash-soil-cement-fiber mixtures (as per Combination 6 shown in Table 5) were tested for each fiber length after 3 days of soaking. The results of CBR are presented in Fig. 20. The curves show that the addition of 1.5% of 12 mm fibers increases CBR value by approximately 74% as compared to that of same mixture without fibers. The CBR values increased with an increase in the amount of fiber up to 1.5%, and thereafter the CBR decreased slightly with the further addition of fibers (Fig. 20). The increase in CBR value was attributable to the fact that fibers contributed significantly to enhance the bearing capacity of the stabilized soil. The highest CBR value is 58%, which is obtained at an inclusion of 1.5% fibers into the stabilized soil, but further additional fiber tends to decrease the CBR value. This behaviour may be attributed to the compaction resistance of the fibers and the fact that the fibers had a lower specific gravity than soils. Nataraj and McManis (1997) noted that the interaction between the soil and the fiber reinforcement controlled the response of the soil/fiber mixture to compaction.

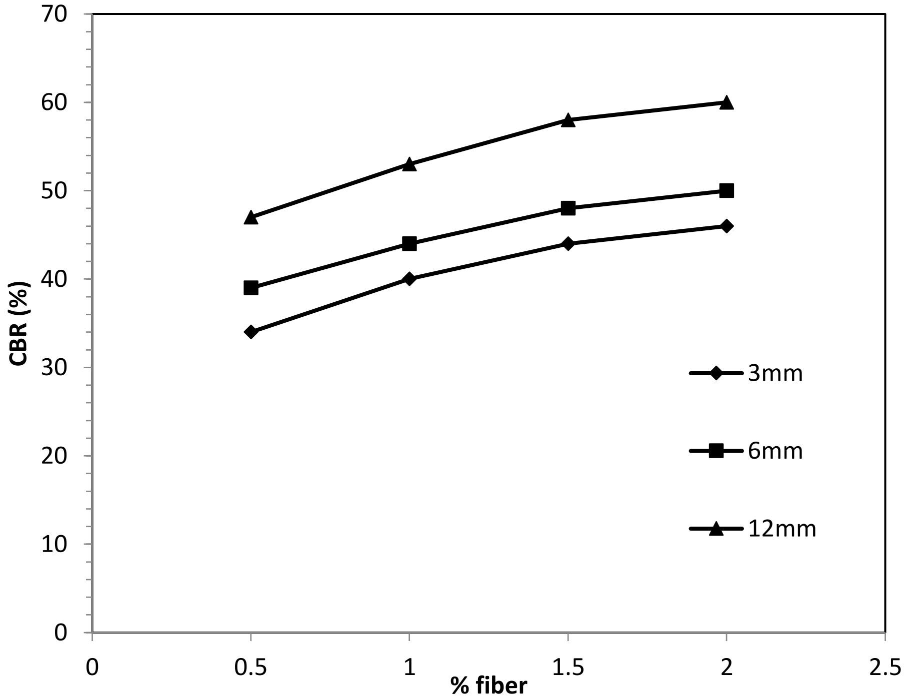

Fig. 20: Variation of California bearing ratio with % fiber.

V. CONCLUSION

In this study different tests like modified proctor compaction tests, unconfined compressive strength tests, split tensile strength tests and California bearing ratio tests were done to evaluate the behaviour of the fibre reinforced and cement stabilized soil mixed with Rice husk ash. The major conclusions drawn are presented below.

- The MDD of cement-stabilized soil–rice husk ash mix slightly decreases with the increase in cement content and OMC increases with increase in the cement content.
- With increase in the RHA content MDD is decreasing, while OMC is increasing. MDD is increasing because of the decrease in the specific gravity of the mix and OMC is increasing because of the higher water absorption of rice husk ash.
- The results of compaction tests showed that limited quantity of polypropylene fibers (0.5–1.5%) had no significant effect on maximum dry density and optimum moisture content of rice husk ash-soil-cement-fiber mixtures
- The higher strength of RHA and Cement stabilized soils compared to natural soil is a result of cementing and pozzolanic properties, respectively.

- 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 rice husk ash-soil specimens compacted at the MDD-OMC state exhibit brittle behaviour in unconfined compression tests. The brittle behaviour is more marked in cement stabilized specimens than in un-stabilized specimens. The fiber inclusions change the behaviour in both instances to ductile behaviour.
- The value of the strengths (UCS and STS) increases with increase in curing period. The rate of gaining the strength in most of the cases are rapid during initial phase of curing, i.e., up to 7 days curing. Strength improvement in case of cement is found to be 326% with respect to un-stabilized/unreinforced soil.
- The stress versus strain curves reveal that at the 12mm size fiber gives higher strength than 3mm and 6mm size fibers. The fibers modifies the stress condition in the specimens and transfer the shear along the failure plane to the surrounding mass by combined effect of adhesion and friction between the fiber and ash particles. Strength improvement is found 154 % at optimum length and content of fiber.
- CBR value of the mix increases with increase in the content of the cement to a certain limit of fiber content (FC = 1.5%) known as optimum content, after which further improvement in the CBR is not significant.
- There has been a remarkable improvement of the CBR value with the admixture of rice husk ash and cement. The CBR value was 6-fold the initial one with the addition of rice husk ash at a content of 10% by weight. The increase in CBR as a function of the rice husk ash content could be attributed to the pozzolanic activity of the rice husk ash. Such a use of rice husk ash would also have the benefit of depositing an agricultural byproduct without negatively affecting the environment

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Appendix B: Notations

- RHA = Rice Husk Ash
- W_S = Weight of Soil
- W_f = Weight of fiber
- Wc = Weight of Cement
- W_P = Weight of pond ash
- W_R = Weight of rice husk ash
- UCS = Unconfined compression test
- STS = Split tensile strength
- XRD = X- Ray Diffraction
- MDD = Maximum dry density
- OMC = Optimum moisture Content.
- CBR = California bearing ratio

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