Micro-structural and Mineralogical studies to Evaluate the Effectiveness of Industrial solid wastes for Stabilization of Expansive Soils

Ramesh H.N[1], Manjunatha B V[2] and Madhavi Gopal Rao Kulkarni[3]

[1,] Professor, Department of Civil Engineering, Bangalore University, Bengaluru - 560056
[2,3] Former Ph. D student Bangalore University, Bengaluru – 560056,
rheddur@yahoo.com1, manjunathmbv@gmail.com2 and madhavit98@gmail.com3

Abstract. Expansive black cotton soils undergo large volume changes due to swell and shrinkage due to seasonal moisture fluctuations during wet and dry seasons causing severe problems to lightly loaded structures, such as buildings, pavements and pipe lines founded on them**.** Before undertaking any construction activity the foundation soil should be properly stabilized. The best way to overcome the problems associated with the expansive soil is by stabilization with pozzolanic materials such as hydrated lime and Portland cement stabilization. However as they may not be economical as well as to reduce the problem of disposal many industrial and agro industrial waste such as Rice Husk Ash (RHA), and Bagasse Ash (BA) and Carbide Lime (CL) which resembles the properties of lime and cement, can be effectively utilized. While they have reactive silica they may not have sufficient lime to produce pozzolanic compounds another waste CL rich in calcium can be amended along with these solid wastes to soil to develop durable strength. Optimization of Rice husk ash and Bagasse ash contents are determined based on un-compressive strength tests. Strength tests carried out by mixing black cotton soil with various percentages of RHA and BA optimum dosages found are 20% and 15% for RHA and BA respectively. Both RHA and BA composed of high silica content, the strength improvement with respect to these additives without CL is marginal due to lack in lime content in them Strength thus enhanced considerably by adding carbide lime. Moulding water content also plays important role in pozzolanic stabilization. A series of strength tests were performed by mixing the black cotton soil with RHA, BA, CL and lime at different water contents and densities compacted with same compactive energy. The strength developed with moulding water content on dry side of optimum condition is more due to the existence of flocculated structure on dry side of optimum condition. The mechanism of strength improvement has been elucidated through microstructural analysis using SEM and XRD studies.

Keywords: Bagasse Ash, Compaction, Expansive black cotton soil, minerals, Structure, Unconfined compression strength

1 Introduction

Expansive soils exhibit swell and shrink behavior along with variation in moisture content owing to the presence of montmorillonite clay with high cation exchange capacity. Thus structures founded on these soils experience severe damages due to high settlements and low bearing capacity. The problem is particularly severe on structures such as canal lining, pavements and light loads. Improvement of the foundation soil becomes inevitable as the option of replacing the foundation with suitable soil becomes tedious uneconomical and involves huge delay. The most viable and sustainable option is by pozzolanic stabilization. Calcium ions and clay particles reacts together to form strong cementitious bonds which binds the clay particles and improves the strength and reduces the compression (10). With lime addition to soil the swelling potential, liquid limit, plasticity index and maximum dry density of the soil are reduced with increase in optimum water content, shrinkage limit and strength. To conserve conventional stabilisers such as lime and cement and to avoid the disposal solid waste with potential to stabilisers various materials such as steel slag, mine tailings, carbide lime, rice husk ash can be used alone or as admixtures. Optimisation of these additives for effectiveness is important and has been studied in this paper. The solid wastes considered are Rice Husk Ash, (RHA), Bagasse Ash (BA) and Carbide Lime (CL).

The processing of sugar cane in sugar mills generates about 26% of bagasse and 0.62% of bagasse ash per every tonne of sugar produced [1] and is available in large quantities. Bagasse ash can be utilized in several viable ways [2-3]. Rice husk ash is produced when rice husk is burnt which is also available in large quantities in agricultural countries such as India. RHA contains high reactive Silica, which can be effectively used in the stabilization process as a pozzolanic material but it cannot be used alone for stabilisation due to lack in lime content [4-5]. Carbide lime (CL) is the bi-product of acetylene-gas industry and is formed by hydrolysis of Calcium carbide [6], it resembles the properties of lime as it contains high amount of calcium hydroxide. It is reported that carbide lime treated soil yields higher strength than the lime stabilized soils [7]. The application of RHA and CL for the field applications can be economical. RHA has been used as an artificial cohesive non swelling (CNS) layer for lightly loaded structure such as foundation and soil subgrade [8]. Similarly CL stabilized soil subgrade shown high bearing capacity and high resilient modulus than quick lime and more economical than quick lime [9]. In this paper admixtures of these wastes to impart good strength of expansive soil is studied.

Field density and water content are important variables and they play important role in the stabilization of soils, particularly in their relationship with compaction compactions parameter. The effectiveness of stabilization at various stabilisers and their admixtures at different water content and densities is studied as function of these parameters at a compactive energy corresponding to Proctor's energy.

2 Material and Methods

2.1 Materials: The source of soil collected and their characteristics as well as those of admixtures used are presented in this section.

Black Cotton Soil. Expansive black cotton soil was collected from Hosakatti village, 25 kms from Hubli, Karnataka, India from a construction site by an open excavation at a depth of 2 m below the ground level. The soil passing through 425 micron BIS sieve, air dried and pulverized in the ball mill. Soil is classified as clays of high plasticity (CH) according to Bureau of Indian Standard (B.I.S).

Bagasse Ash (BA). is collected from Koppa sugar industry, Mandya district, Karnataka, India. Bagasse ash collected from conveyor belt of sugar industry, the organic content bagasse ash is removed by burning in oil-fired furnace at Technomet Solutions, Peenya industrial area at a temperature of 600^0 Centigrade for 8 hours. The ash has a 66% Silica, 12% Alumina and CaO of 5.6%.

Rice husk ash (RHA). was collected from Davanagere District, Karnataka State. Rice husk ash produced from this rice mill is having particle size less than 425 micron and is directly used after oven drying for a period of 24 hours. RHA is rich in silica (85%) and low in calcium (CaO of 1%).

Carbide Lime (CL). used in this study is collected from an oxy- acetylene gas welding plant near Gottigere Hobli of Bangalore urban District in Karnataka State. The carbide lime used in the study is collected from fresh deposit in the disposal region. The physical properties and chemical composition of carbide lime are presented in Table 6. Carbide Lime is rich in CaO (83%) and low silica (5.7%)
The commercially available Hydrated Lime has a minimum assay of 90% of $Ca(OH)_2$

The physical properties of Soil, BA and RHA are summarized in Table 1.

Table 1. Physical Properties of Soil, BA and RHA

Property	Soil	BA	RHA
Colour	Black		Grey
Specific gravity	2.65	1.71	1.95
Sand (4.75–0.075 mm) (%)	4	12.0	Nil
Silt (0.075–0.002 mm) (%)	36	66.4	72
Clay (<0.002 mm) (%)	60	-	18
Liquid limit (%)	91	61	
Plastic limit (%)	39	--	
Plasticity index (%)	52	--	
Shrinkage limit (%)	11	-	
Optimum moisture content (%)	32	43	
Max. dry unit weight (kN/m^3)	12.95	10.3	
Unconfined compressive strength, (kPa)	180	--	

2.2 Methodology

The test procedures to conduct various laboratory tests are briefly described.

Preparation of Dry Soil Sample. The dry samples for various tests have been prepared as per the procedure [11]**.** The fraction of soil passing through 425 micron has been used for the determination of Atterberg's limits. **Water Content** Water content of the soil has been found out as per as per the procedure [11]. **Specific Gravity** Specific gravity of the soil has been found out by density bottle as per as per the procedure [11]. **Atterberg's Limits.** The Atterberg's limits have been determined as per the procedure [11]. The soil is sieved through 425 micron BIS sieve.

Compaction Test. The compaction test has been carried out using mini compaction test apparatus as per the procedure [12].

Unconfined Compression Test. Unconfined compressive strength (UCS) tests are performed as per the procedure [13]. A constant strain rate of 1.25 mm/minute is maintained for the testing of specimens. The tests have been carried out for three similar specimens and peak stress values reported are the average.

Preparation of samples for determination of Un Compressive Strength at Proctor's optimum conditions and at different moulding water contents and dry densities

. Two series of tests are conducted: 1. to arrive at optimum additive contents and 2. To determine the role of moulding water content and dry density.

For the first series, the soil is mixed with varying additive contents and compacted at Proctor's optimum water content and compacted to maximum dry density and their UCS determined without any pre curing and after curing for one week and optimum content obtained.

For the second series the soil is mixed with optimum amount of additive/admixtures at three different water contents viz., at optimum, dry side and wet side of optimum and compacted to their respective dry density corresponding to the same compactive effort. Their UCS determined without any procuring and curing for one week. The moulding water content and density used for this series is given Table 2 and Table 3.

3 Results and Discussion

3.1 Bagasse ash and Lime

Addition of Bagasse ash improved the strength of soil marginally without any pre curing. Even though the samples were tested without any precuring, a marginal improvement in strength is observed probably due to some time elapsed during mixing and sample preparation before the test is performed by the pozzolanic reaction that would have taken place between reactive silica and free lime content of bagasse ash (5% bagasse ash) present in it as it is reported in case of stabilization of soil with lime alone [19]. Further improvement in strength is observed when bagasse ash is added up to 15%. However with further increase in BA reduction in strength is seen as shown in Fig 1. This may be due to insufficient clay available for reaction with increased amounts of reactive silica and lime [2]. With any BA content improvement in strength is seen with curing for 7 days of curing period. Even after curing the strength does not increase beyond 15% of BA addition. Thus the optimum BA content for the soil used is taken as 15%.

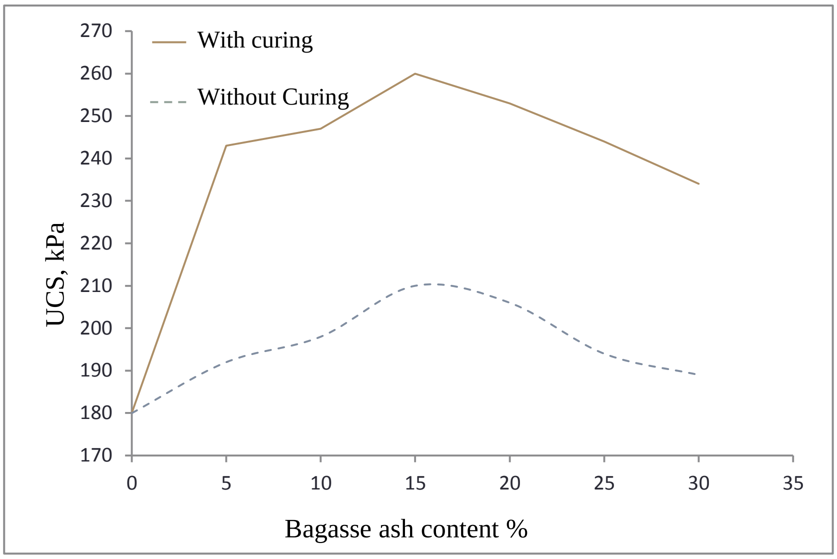

Fig. 1. Variation of Unconfined Compressive Strength of Soil with Varying Bagasse Ash Contents on without curing and with7 Days of Curing

With the addition of optimum dosage of bagasse ash, the strength improvement is not significant; hence lime is added to soil and bagasse ash mixture to bring about enhanced pozzolanic reaction. In the presence of water, calcium from lime reacts with silica and alumina from bagasse ash and clay, forms cementitious compounds calcium silicate hydrate and calcium aluminate hydrate (CSH and CAH). Due to the formation of theses pozzolanic compounds, the strength properties of soils are enhanced. Addition of 1% lime to B.C soil-optimum bagasse ash mixture, increase in the strength of 29% is observed on immediate testing is as shown in Fig 2. This is because of formation of C-S-H amorphous compound with an amorphous structure. With the further increase in lime content up to 4%, the strength increased. Beyond 4% lime content, decrease in strength is observed and this may be due to the insufficient amount of clay particles for completer utilization of pozzolanic compounds formed such as C-S-H gel. Thus optimum lime content for the soil with 15% of BA is taken as 4%, The lime content at which the predominant formation of C-S-H amorphous compound ceases corresponds to the optimum lime content [20]. After 7 days of curing, further improvement in strength has been observed and at 5 % of lime content, the strength improved 5 folds compared to that of the soil bagasse ash mixture because pozzolanic reactions are time dependent. With the further increase in lime up to 5%, the strength increased and the rate of strength improvement decreased beyond 4% of lime content and hence 4% lime is chosen as the optimum dosage in the present investigation.

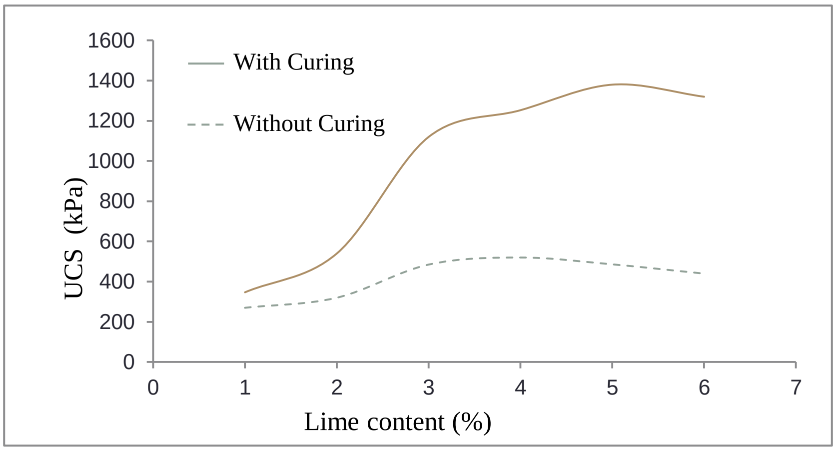

Fig. 2. Variation of UCS of Soil and Bagasse Ash Mixture with Varying Lime Content on without curing and after curing for 7 days

3.2 Rice husk ash and carbide lime as stabilizers for BC soil

Studies are also conducted on soil with RHA alone and with CL as admixture.

The type of studies conducted are similar to those conducted with BA and lime except that in this case instead of commercial lime CL is used as admixture to supplement calcium ions. The studies revealed that the optimum RHA content with and with CL is 20%. Also the increase in the strength at any RHA content is more after curing than the samples tested without curing. Addition of CL further increases the strength with or without curing. The optimum CL content is found to be 8%.

3.3 Influence of Moulding water content and dry density on strength properties of Expansive black cotton soil

Strength properties of expansive B C soil treated with bagasse ash and lime compacted at moulding water contents. The dry unit weight and water content at dry of optimum, optimum and wet of optimum conditions have been selected based on compaction test results of the respective combinations on either side of the compaction curve. The water contents corresponding to 95% of maximum dry unit weight are selected on the dry side and wet side of optimum and the corresponding values of water content and dry unit weight values are tabulated in Table 2.

Table 2. Compaction parameters of Black Cotton Soil Treated with Bagasse Ash and Lime chosen for strength tests

Mixture	Dry of optimum		Optimum		Wet of optimum	
	Unit weight (kN/m^3)	Water content (%)	Unit weight (kN/m^3)	Water content (%)	Unit weight (kN/m^3)	Water content (%)
B.C soil alone	12.30	26	12.95	32	12.3	38
B.C soil + 15% BA	12.75	30	12.75	33	12.75	35
B.C soil + 15% BA + 4% lime	11.82	28	12.45	35	11.82	41

Effect of Bagasse ash and lime on strength properties of Black cotton soil compacted at different moulding water content. The strength parameter of expansive soil treated with optimum dosage of bagasse ash is as shown in Fig 3. The strength of black cotton soil with the addition of optimum dosage of bagasse ash, increased from immediate testing to 90 days of curing period at dry of optimum and at wet of optimum conditions. It can be observed that the strength of black cotton soil-bagasse ash composite on dry side of optimum is more significant as compared to optimum and wet of optimum conditions. This may be attributed to the flocculation of particles is more significant on dry side of optimum. Flocculation of particles takes place for the soil with the addition of bagasse ash because of the pozzolanic reaction between silica and alumina of soil and bagasse ash mixture and also free lime content present in bagasse ash. Since the unconfined compressive strength will be different at different water content, to assess an increase in strength due to pozzolanic reaction [19].

The strength of expansive soil and bagasse ash mixture treated with lime varied from dry of optimum to wet of optimum conditions without curing. With an increase in curing period up to 90 days, the strength increased for the samples compacted at dry of optimum, optimum and wet of optimum conditions respectively is as shown in Fig.4. This may be attributed to the reaction between reactive silica of soil and bagasse ash mixture and lime producing cementitious products. With further curing upto 90 days, significant improvement in strength of 3.73, 3.7 and 7 folds is seen at dry of optimum, optimum and wet of optimum conditions respectively which may be attributed to the cluster of cementitious compounds with curing and also pozzolanic reactions are time dependent.

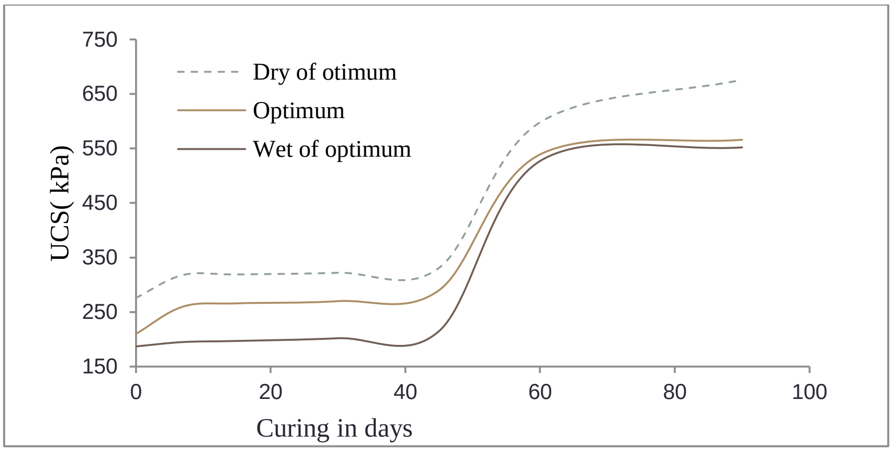

Fig. 3. Variation of Strength Properties of Soil Treated with Bagasse Ash Compacted at different Moulding Water Contents with Curing Period

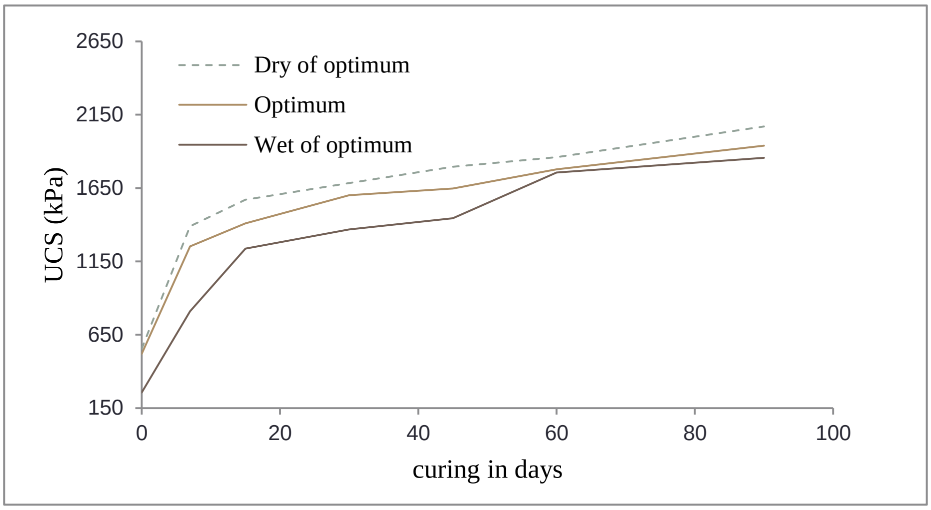

Fig. 4. Variation of Strength of Soil and Bagasse Ash Mixtures Treated with Lime compacted at different Moulding Water Contents with Curing Period

Effect of Rice husk ash and carbide lime on strength properties of Black cotton soil compacted at different moulding water content. Specimens were moulded for three significant combinations of moisture content and corresponding dry unit weight. The dry unit weight and moisture content adopted for BC soil are shown in Table 3. Unconfined compressive strength is determined immediately after moulding and after curing for 7, 30, 60, 90 days. During the process of curing, specimens were stored in desiccators under relative humidity of 100%.

Table 3. Compaction parameters of BC soil and RHA treated with CL compacted at three significant moulding water content

Combination	Dry of Optimum		Optimum		Wet of Optimum	
	Dry unit weight kN/m^3	Moisture Content %	Dry unit weight kN/m^3	Moisture content %	Dry unit weight kN/m^3	Moisture content %
BC soil alone	12.30	24	13	32	12.30	40
BC soil + 20 % RHA	12.11	28	12.75	34	12.11	40
BC soil + 20 % RHA + 8% CL	11.74	30	12.36	36	11.74	42

The variation in strength of BC soil stabilized with RHA compacted at different moulding water content is shown in Fig 5. The strength of BC soil - RHA mixture i.e. 20% compacted on dry side of optimum is higher and varies from 301 kPa to 325 kPa for immediate to that of 90 days of curing period than compacted on optimum and wet side of optimum. Strength at optimum and wet of optimum varies from 274 kPa to 306 kPa and 166 kPa to 236 kPa for immediate to that of 90 days of curing period respectively. This is due to flocculated structure of composite when compacted on dry of optimum and also the effect of curing is negligible in soil mass and RHA mixture [20]. Addition of RHA increases the strength of BC soil, since RHA is an inert material and possess angular and sub angular particles which agglomerates the particle into larger size of the composite by increasing the angle of internal friction of the composite results in increase in the strength [17].

The strength of BC soil stabilized with RHA and carbide lime mixture i.e. 20% and 8% compacted on dry side of optimum is higher and varies from 393 kPa to 2602 kPa for immediate to that of 90 days of curing period than that of compacted on optimum and wet of optimum. Strength at optimum and wet of optimum varies from 292 kPa to 2359 kPa and 218 kPa to 1980 kPa for immediate to that of 90 days of curing period respectively. Addition of RHA is only a mechanical stabilization due to the deficiency in the lime content, to improve strength properties carbide lime is added. The calcium hydroxide obtained from the hydration of free lime from carbide lime dissociates in water. Hydroxyl ion concentration increases with increase in pH concentration. The increase in pH accelerates the formation of cementitious compounds, which increases the strength of the soil. The alumina and silica from both soil and RHA gradually react with the calcium ions from the hydrolysis of CaO to produce insoluble pozzolanic compounds like calcium silicate hydrate (C-S-H) and Calcium aluminate silicate hydrate (C-A-S-H). Formation of these compounds eliminates the void pores in the stabilized soil matrix and the gel so formed hardens with time there by increases the strength of the soil matrix [21] and [18]. The strength of sample compacted on dry side of optimum is more compared to those compacted at optimum and wet of optimum this is due to flocculated structure of composite when compacted on dry of optimum and the results are shown in Fig 6. [20].

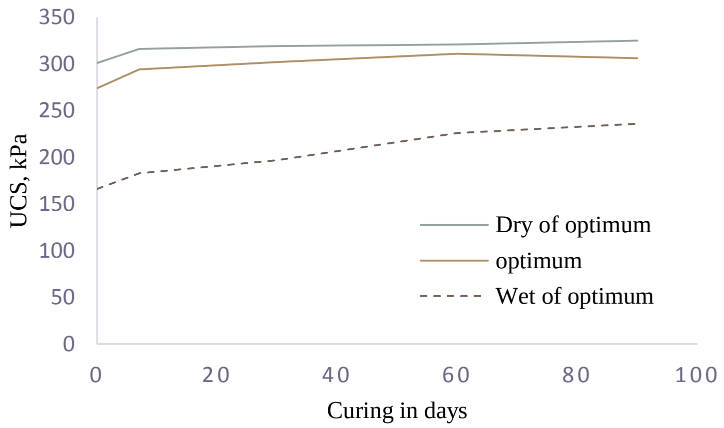

Fig. 5. Variation of Strength of Soil Treated with Rice husk Ash Compacted at different Moulding Water Contents with Curing Period

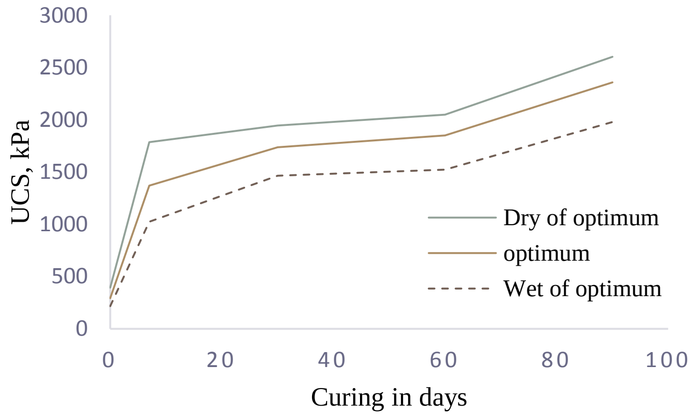

Fig. 6. Variation of Strength of Soil Treated with Rice husk Ash and carbide lime Compacted at Moulding Water Contents with Curing Period

3.4 Mineralogical and microstructural studies of soil stabilized with industrial wastes and lime

The changes in strength properties of soil with the addition of bagasse ash, bagasse ash and CL; RHA, and lime are studied in detail. Variation in strength properties is mainly due to the amount of pozzolanic compounds formed by pozzolanic reaction between soil and additives and microstructural changes. To understand better the mineralogical, microstructural and chemical composition changes are studied through XRD, SEM and EDAX analysis.

XRD analysis of BC soil stabilized with Bagasse ash and lime. The XRD pattern of expansive black cotton soil shows the minerals montmorillonite, quartz and aluminum oxide. Montmorillonite is found at d spacing of 4.45 A^0, 2.56 A^0 and 1.49 A^0 at Bragg's angle of 19.5^0, 34^0 and 62^0 respectively and Quartz at 4.25 A^0, 3.34 A^0, 2.81 A^0, 1.67 A^0 and 1.38 A^0 at Bragg's angle of 20^0, 37.5^0, 55^0, 67.5^0 and 72.5^0 respectively and confirms the presence of montmorillonite, quartz and aluminum oxide, are the chief clay minerals in expansive black cotton soil as seen from Fig. 7.

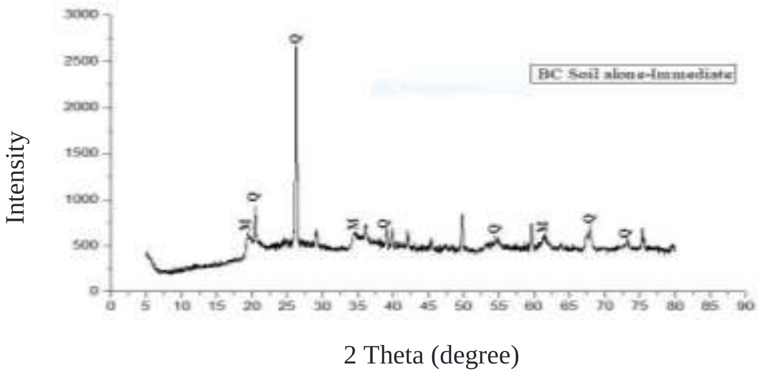

Fig. 7. XRD Pattern of Soil

The strength of B.C soil and bagasse ash mixture treated with lime increased from immediate testing to curing period of 90 days. Enhancement in strength is attributed to the reaction between reactive silica of soil and bagasse ash mixture and lime, producing cementitious products such as CSH and CASH gel products, which is being confirmed by XRD pattern is shown in Fig.8.

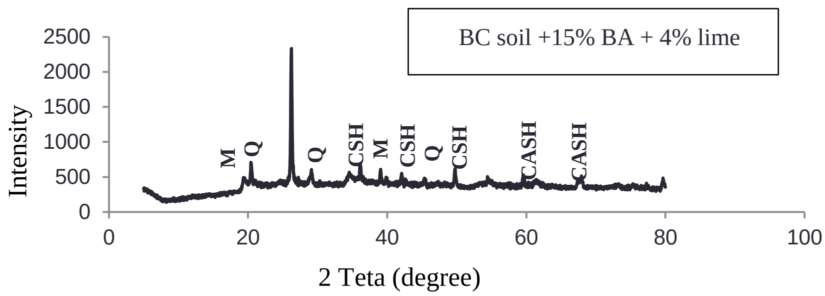

Fig. 8. XRD Pattern of Soil and Bagasse Ash Mixture Treated with Lime and cured for 90 Days.

The appearance of the peak at two theta angles of 34.72^0 and 40.2^0 with d spacing of 2.5814 A^0 and 2.2376 A^0 confirm the formation of CSH compounds. XRD pattern, shows the formation of CASH compounds at two theta angles of 59.6^0, 67.72^0 with d spacing of 1.5498 A^0 and 1.3825 A^0. As compared to the XRD pattern of black cotton soil, the peaks became very sharp with the addition of bagasse ash and lime which is shown in Fig. 8. The XRD patterns gives the strong evidence of the formation of CSH and CASH compounds which plays accounts for drastic boost in strength of B.C soil bagasse ash –lime mixtures.

SEM analysis of BC soil stabilized with Bagasse ash and lime. SEM image of expansive black cotton soil is as shown in Fig. 9, it is found that the structure of soil is flaky with thin films and the voids in the soil matrix are larger and flakey structure with equal dimensions with thin diagram which again shows that the chief mineral constituent in the soil is montmorillonite due to which it is expansive in nature.

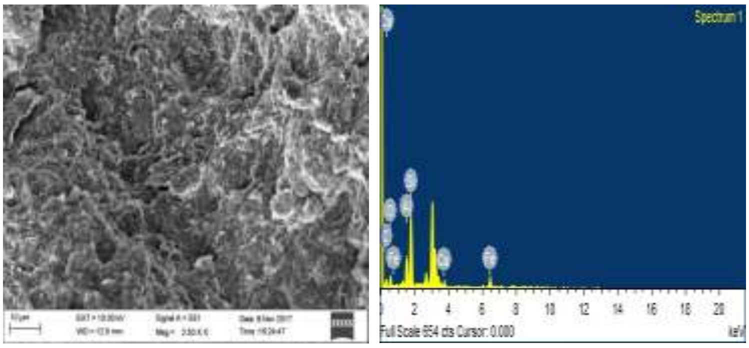

Fig. 9. SEM And EDAX Image of Soil

The highly magnified view of the expansive soil-bagasse ash-lime combination of the samples cured for 90 days of curing period is shown in Fig. 10.

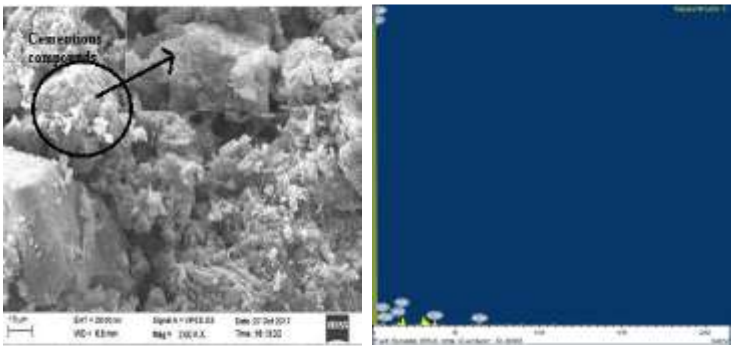

Fig. 10. SEM and EDAX Image of Soil and Bagasse Ash Mixture treated with Lime and cured for 90 Days

The highly magnified image (10000 X) shows the flocculated particles with packets of quartz. The highly magnified image of soil-bagasse ash-lime mixture indicates the formation of C.S.H and C.A.S.H gels which are confirmed by XRD analysis and these cementitious compounds are in fused state, C.S.H and C.A.S.H gels have extended into the pore space and reduced the void spaces. With the addition of lime, more calcium ions are released into the system and as a result, bagasse ash is dissolved into the system at higher rate and increased white patches of cementitious products are seen.

XRD analysis of BC soil stabilized with Rice husk ash and carbide lime. XRD pattern of BC soil stabilized with RHA at 90 days of curing period is shown in Fig 11.

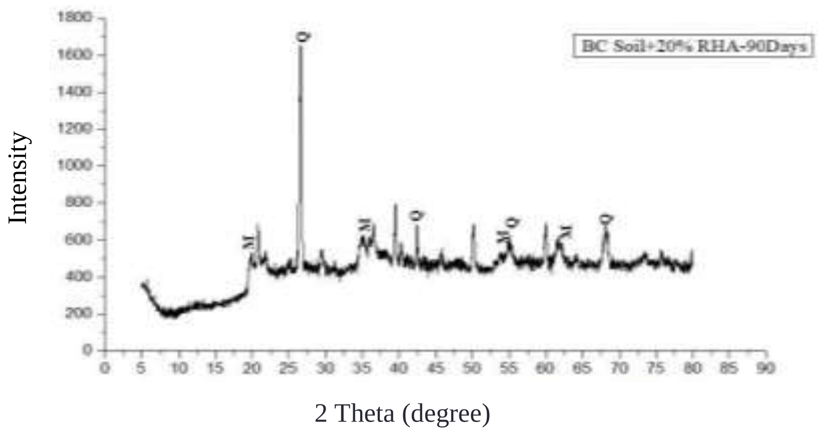

Fig. 11. XRD spectrum for soil+20%RHA mixture after 90days of curing

The powdered sample of the mixture shows a crystal mineral of montmorillonite (M) at a d-spacing of 4.45, 2.56, 1.69, 1.49 θ and, quartz (Q) are showing at a d-spacing of 3.34, 1.67, 1.38, 1.28, 2.81 θ respectively. Addition of RHA is a mechanical stabilization and hence strength improvement in the stabilizing process is very minimal and it is due to the agglomeration of soil and RHA particle. Compared to the soil alone addition of RHA shows more pronounced peak due to the presence of dominant mineral quartz (Q), However the strength of blended composite is not significantly improved due to the absence of Calcium oxide (CaO) content . Hence the stabilization with the addition of RHA alone is mainly by structural changes.

The changes in micro structural development of soil due to addition of additives play a significant role in enhancing the strength of soils. Addition of RHA in strength gaining process is very limited due to its low calcium oxide content. Introduction of carbide lime to the stabilized BC soil and RHA shows a significant improvement in its strength due to increase in the cohesive property. When the carbide lime introduced the CaO of the carbide lime reacts with water and leads to the calcium hydroxide, the hydroxyl of the solution increases pH and inturn causes releases more reactive silica resulting in the formation of cementitious compounds such as calcium silicate hydrate (C-S-H) and calcium aluminate silicate hydrate binding the soil particles [22]. The strength of the soil mass also increases due to reduction in the void ratio also. The main cementitious gel formed with the addition of carbide lime with products such as C-S-H and C-A-S-H formed at a d spacing of 4.07, 2.25, 1.808, 1.451, 1.366, 1.24 θ and 3.05, 2.74, 2.14, 1.66 θ respectively are seen in Fig. 12.

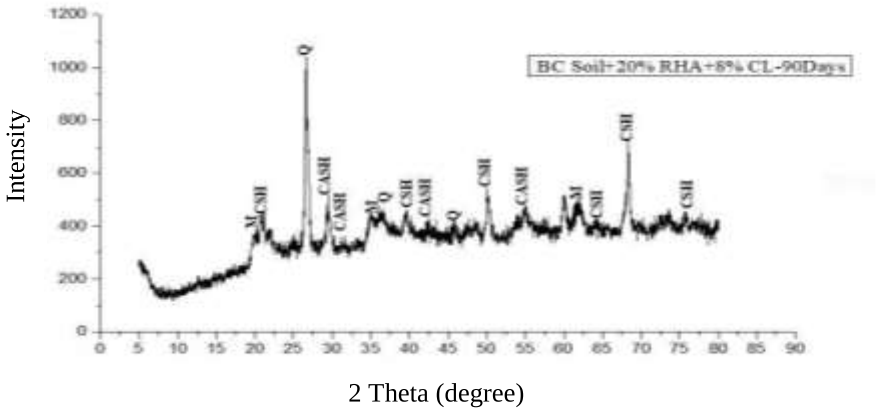

Fig. 12. XRD spectrum for soil+20%RHA+8% CL mixture cured for 90days

SEM analysis of BC soil stabilized with Rice husk ash and carbide lime. RHA poses angular and sub angular particle addition of RHA leads to increase in the frictional property (angle of internal friction) of the material and decreases the cohesion value of the blend which agglomerates the particle into larger size thus there is a slight improvement in the strength were observed from the UCS results [17]. Addition of RHA into the soil samples is a mechanical interlocking effect which brings changes in the soil structure, as seen from the Fig 13. The images were magnified at 2500x magnification and it can be observed from SEM images that, there is an angular and sub angular particle which reduces the pore air void spaces of the sample within the soil and changes the soil structure by agglomeration which increases the marginal improvement of strength of BC soil.

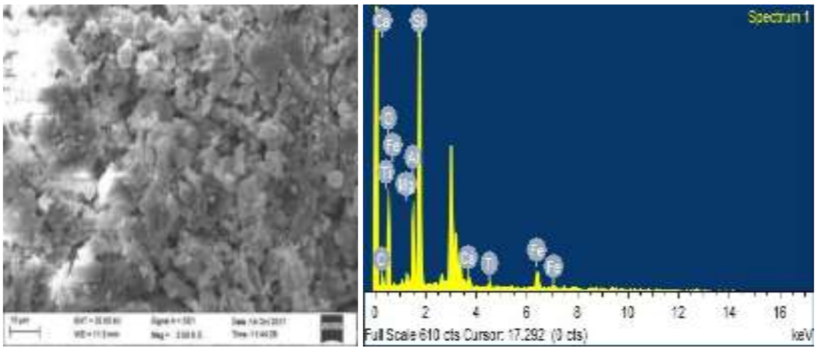

Fig. 13. SEM image and EDX micrograph Soil+20% RHA mixture after curing for 90 days

Addition of RHA is just a mechanical interlocking effect, in order to improve the strength to a great extent lime rich additives are to be added among one is carbide lime. Addition of carbide lime at an optimum dosage of 8% increases the strength of the blend, this is due to addition of carbide lime to the soil and optimum RHA mixture increases the pH dissolving the silica from the composite and reacts with calcium ions from the carbide lime leads to the formation of gel C-S-H and C-A-S-H which hardens with the time thus increases the strength of the mixture and it is verified from the XRD analysis. The cementitious gel is formed which fill the void spaces within the sample, this phenomenon occurs due to coating and binding of individual soil particles with cementitious gels resulting in the reduction in migration of ions into the pores resulting in a rigid structure. The morphology of the 90-day samples is shown in Fig 14.

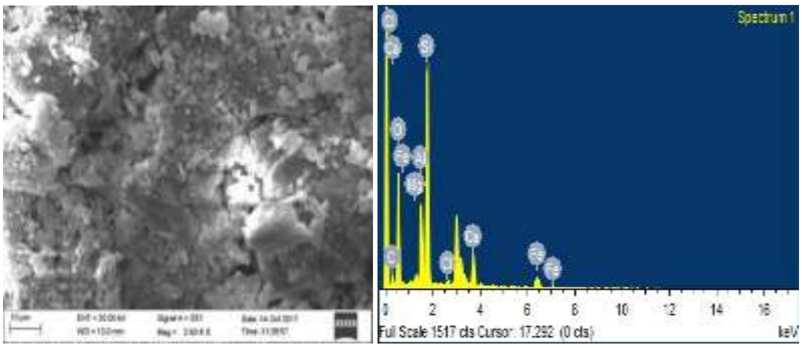

Fig. 14. SEM image and EDS micrograph of soil+20% RHA+8% CL mixture after curing for 90 days

It is denser than the RHA treated sample of the 90-days curing period by filling of the cementitious products in the pore space. The denser morphology with curing time leads to strength increase [22].

4 Conclusions

The following are the major conclusions are drawn for the detailed studies reported:

1. Addition of bagasse ash alone improves the strength marginally. Optimum BA is found to be about 15%. The relatively less improvement with BA has been explained as due to less amount of calcium content of the BA though contains sufficient reactive silica. The strength improves with curing period better with lime. However the optimum BA content for uncured and cured samples is almost the same. With the incorporation of different percentages of lime to soil-optimum bagasse ash mixture, the unconfined compressive strength increase on both uncured and cured samples. The optimum lime content is about 4%. The changes are in consist ant with SEM and XRD studies. Thus it is concluded that CL with sufficient lime content would be highly beneficial.
2. The tests on soil with different amounts of RHA alone have shown that without addition of lime is about 20% with or without curing. However the strength of soil with RHA and CL is much higher than without BL but the optimum BA is about the same. This is again due to better production of cementitious compounds in the presence of CL. The optimum CL content for both cured and uncured samples is about 8%. The study clearly shown that CL can be effective replacement for lim.
3. The variation in the strength of soil with optimum contents has shown that the strength mobilisation is better when the samples are compacted at water content on dry side of the optimum than at optimum or wet of optimum water content itself. This has been explained as due to flocculation of soil particles on dry side of the optimum water content facilitating better cementation with pozzolanic compounds formed. The study brings out that apart from pozzolanic binding the fabric soil particles due variation in the water content even plays important role.
4. It is observed that the ratio of strength of soil to the strength soil without additives compacted at water content on wet of optimum with any additive is higher than on soil compacted on dry side of optimum water content as the strength of soil at wet of soil is far less than the soil when is compacted on dry side of the optimum water content. However the effect of moulding water content and density is much less in the case of RHA s due to its higher pozzolanic reactivity.
5. The variation in the strength of the soil with different additives and admixtures are consistent with pozzolanic compounds formed but no attempt is made to correlate the strength with pozzolanic compounds formed quantitatively.

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