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Application of Suitable Admixtures (Lime and RHA) for Improvement of Pavement Subgrade

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Abstract

The quality of a pavement depends on the strength of its sub-grade. The present investigation has been carried out with easily available materials like lime and rice husk ash mixed individually and in combinations with different proportions. The different percentages of lime with respect to weight of dry soil were 2%, 4%, 6%, 8% 10% and for rice husk ash (RHA) were 3%, 6%, 9% and 12%. In each case the stabilized soil was compacted at optimum moisture content (OMC). In each case California Bearing Ratio (CBR) tests and in case of compaction at OMC Unconfined Compressive Strength (UCS) tests were performed. The effect of curing on UCS samples upto 180 days with the intervals of 30 days was also studied. It was found that CBR of original soil improved from 4.25% to a maximum value 28.25% when mixed with combination of 6% lime and 9% rice husk ash (RHA) under unsoaked conditions and from 3.5% to 29.82% when mixed with a combination of 6% lime and 6% rice husk ash (RHA) with respect to dry weight of soil under soaked conditions at optimum moisture content (OMC). The unconfined compressive strength (UCS) of original soil was improved by 253% when mixed with 6% lime and 6% rice husk ash (RHA).However the maximum value of UCS is attained by a value of 285% when mix proportion of 4% lime and 9% rice husk ash. Based on the laboratory test results correlations have been developed between California Bearing Ratio (CBR) at optimum moisture contents as function of different soil parameters by multiple linear regression models. To gain an insight into the reasons of strength increase by identifying the microfabric structure of soil and soil-lime-RHA mixes, semi quantative analysis with X-ray diffraction (XRD) and X-ray fluorescence (XRF) were conducted. The interpretations of results of XRD and XRF tests have clearly indicated that change in strength between lime and rice husk ash admixture occur due to change in silica and mica contents. It is concluded from this study that desired CBR and UCS values may be obtained on mixing a limited quantity of lime with soil when rice husk ash is also used as an auxiliary stabilizer making the mix cost effective.

Keywords: pavement, soil, lime, RHA

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INTRODUCTION

Need of pavement construction on soft sub-grade calls for improvement of geotechnical behavior of the sub-grade prior to the construction. The most popular methods to improve soft soil is by stabilization with addition of different cheap and locally available alternative materials, such as rice husk ash, fly ash, morrum and the like. In this study an attempt has been made to improve the soft clayey soil with cheap and locally available materials like rice husk ash and if needed with conjunction of lime in limited quantity.

Rice husk is an agricultural waste material obtained from milling of rice. About 770 million tons of rice husks are produced annually in Asia. In India it is approximately 120 million tons. In developed countries, when the mills are typically large, disposal of the husks is a big problem for the environment and also burning in open place is not desirable. This waste material, if suitable, can be used for the economic utilization in construction of road sectors. A systematic detailed investigation should be undertaken to make possible use of rice husk ash (RHA) particularly in weak or soft soils to enhance the quality of such soil so that such improved soil can be cost effective for constructions works.

Another stabilizing material is lime, which improves the soil much by its little addition by pozzolanic reaction which occurs to improve the soft soil. Lime reduces the plasticity index of highly plastic soils making them more friable and easy to be handled and pulverized. There is generally an increase in Optimum Moisture Content and decrease in Maximum Dry Density but the strength and durability increases. Hydrated (slaked) lime is very useful in treating heavy, plastic clayey soils. Lime may be used alone or in combination with cement, fly ash, or other pozzolanic materials like rice husk ash.

Again due to the rapid economic growth and industrialization throughout the world, a huge quantity of waste materials (agricultural, industrial and others) all over the world are being generated, creating a tremendous negative impact on the environment as well as public health and ecology system. So the safe disposal of these waste materials is very vital issue and challenging task for the Engineers and Technologists. Such situation can be well mitigated by the bulk utilization of such waste materials mainly in the field of construction. Many investigators have carried out research in this area for last few years. Some salient works in this regard are presented as follows:

Roy conducted the study of soil stabilization by using the rice husk ash (RHA) and cement. The experimental study shows the suitability of locally available materials like RHA to be used in the construction industry. From the experimental results it was found that the unsoaked CBR value was improved by 106% at 10% RHA and 6% cement and after that it slightly decreased. The similar trend needs to be found in case of UCS which also shows an improvement of 90.6% of the same mix proportions. According to the investigator the maximum improvement in strength of soil occurs on mixing the soil with 10% RHA and 6% cement as an optimum amount.[1]

Biswas investigated the effects of adding RHA and lime in sub-grade soil of a rural road. They conducted that RHA can be effectively utilized for back filling and making sub-grade of roads. Their results show that little addition of lime with RHA can significantly improve the engineering properties of weak sub-grade soil. Moreover it also improves the water proofing characteristics of soil. They also concluded that curing period has marked the influence in the Strength and durability character of soil.[2]

Sabat investigated the effects of randomly distributed polypropylene fibre on engineering properties of expansive soil stabilised with RHA and Lime. The experimental results show that on addition of fibre with RHA-Lime stabilised soil MDD goes on decreasing and OMC goes on increasing. The UCS, soaked CBR and split tensile strength values were found to increase with increase in percentage of fibre upto 1.5% and further addition of fibre decreases the above values. The addition of fibre was found to decrease swelling pressure and increasing durability.[3]

Okafor *et al.* performed laboratory experiments to study the effects of RHA on some geotechnical properties of a lateritic soil to be used for subgrade. The test result shows that RHA increased the OMC but decreased the MDD of the soil. The addition of RHA improved the strength property (CBR) of the soil. The 10% RHA content was observed to be the optimum content for the lateritic soil.[4]

Alhassan carried out extensive laboratory experiments to investigate the effect of lime and RHA on permeability and strength properties of lateritic soils. Effects of the ash on the soil lime mixtures were investigated with respect to Unconfined Compressive Strength (UCS) and coefficient of permeability. His findings indicate that no more than 6% RHA can be used to increase UCS and reduce permeability of lateritic soil.[5]

The present investigation has been carried out to study the strength improvement of soft soil for the construction of flexible pavement. Subgrade soil may be mixed with the locally available materials such as lime and rice husk ash in isolation and also in different combinations. In this respect soft soil was collected from 2.5 to 3.5 m below the ground level in Bidhannagar in K.M.C area. The major parameter for determining the strength improvement of soil is California Bearing Ratio (CBR) under soaked and unsoaked conditions at the optimum moisture contents and corresponding Unconfined Compressive Strengths (UCS) with the effect of curing period. Based on the laboratory test data an attempt has been made to develop a correlation of CBR as a function of different soil parameters such as atterberg limits, compaction characteristics and strength by multiple linear regression analysis.

Further attempt has also been made to gain an insight into the reasons of strength increase of the soft soil by identify the microfabric structure by conducting out semi quantative analysis with X-ray diffraction (XRD) and X-ray fluorescence (XRF) analysis. The interpretations of results of XRD and XRF tests have clearly indicated the reason of change of strength of soil-lime-RHA mixes with change of contents of lime and RHA.

MATERIALS USED

The materials used in the present study were locally available clayey soil, lime and rice husk ash. The physical properties of these materials are summarized one by one as follows:

Soil

The soil used for this study was collected from Bidhannagar in Kolkata Municipal Corporation area in West Bengal, India at a depth of 2.5 to 3.5 m below the ground level using the method of disturbed sampling. The engineering properties of the soil used in this study are given in Table:1 and XRD pattern of the soil sample is presented in Figure 1.

Table 1. *Engineering Properties of Soil*

Basic Properties of Soil	**Value**
Sand (%)	5
Silt (%)	68
Clay (%)	27
Liquid limit (%)	51
Plastic limit (%)	28
Plasticity index (%)	23
IS classification	CH
Specific gravity	2.65
Maximum dry density(gm/cc)	1.63
Optimum moisture content (%)	15.92
CBR at OMC unsoaked (%) at OMC	4.25
CBR at OMC soaked (%) at OMC	3.50
Unconfined compressive strength(UCS) (kN/m^2)	98

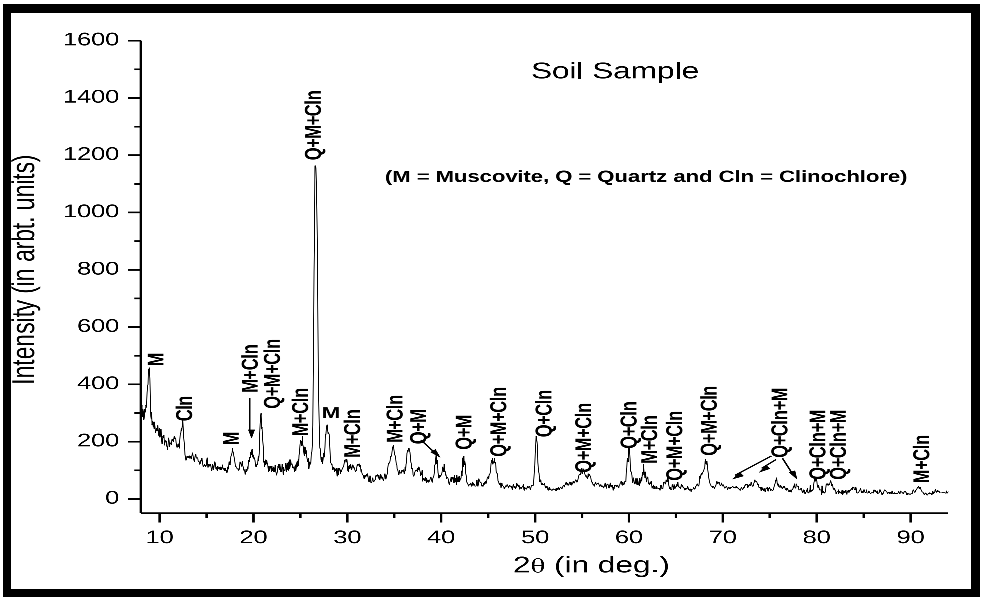

Fig.1. *X-ray Diffraction (XRD) Pattern of the Soil Sample.*

It appears from the above X-ray diffraction (XRD) patterns of the soil sample shows that the starting soil sample contains crystalline quartz, mica and clinochlore.

Lime

The hydrated lime used in this study was obtained from the local market at Jadavpur, Kolkata. Its Chemical properties as obtained from XRF analysis are presented in Table 2 and XRD analysis is presented in Figure 2.

Table 2. *Chemical Properties of Hydrated Lime (from XRF Analysis).*

Constituents	Weight percentage
SiO_2	38.271
Fe_2O_3	0.189
CaO	57.857
K_2O	0.065
MgO	0.643
TiO_2	0.026
Na_2O	0.076
SO_2	2.873

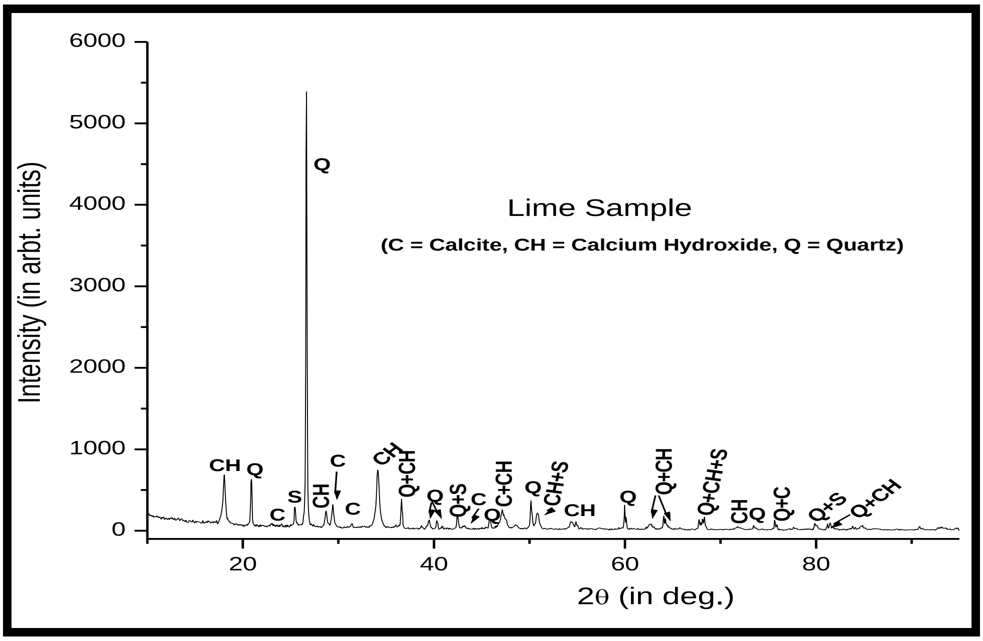

Fig.2. *X-ray Diffraction (XRD) Pattern of the Hydrated Lime.*

The XRD pattern of the used Lime shows that it contains Calcite (Calcium Carbonate), Silica (Quartz), and Calcium Hydroxide and Sulphur dioxide (SO_2). It also appears from the figure that silica content of the lime is quite high.

Rice Husk Ash (RHA)

Rice husk is an agricultural waste material obtained from milling of rice, in India it is approximately 120 million tons. In this study the rice husk ash (RHA) was obtained from local rice mill at the Bashirhat sub division in North 24 Parganas District of West Bengal, India. The Physical properties of RHA are given in Table 3 and XRD pattern of RHA is presented in Figure 3.

Table 3. *Physical Properties of RHA.*

Basic properties of RHA	Value
Liquid limit (%)	NP
Plastic limit (%)	NP
Plasticity index (%)	NP
Specific gravity	1.96
Maximum dry density(gm/cc)	0.85
Optimum moisture content (%)	32
Angle of internal friction(°)	38
CBR at OMC unsoaked (%)	8.75
CBR at OMC soaked (%)	8.15

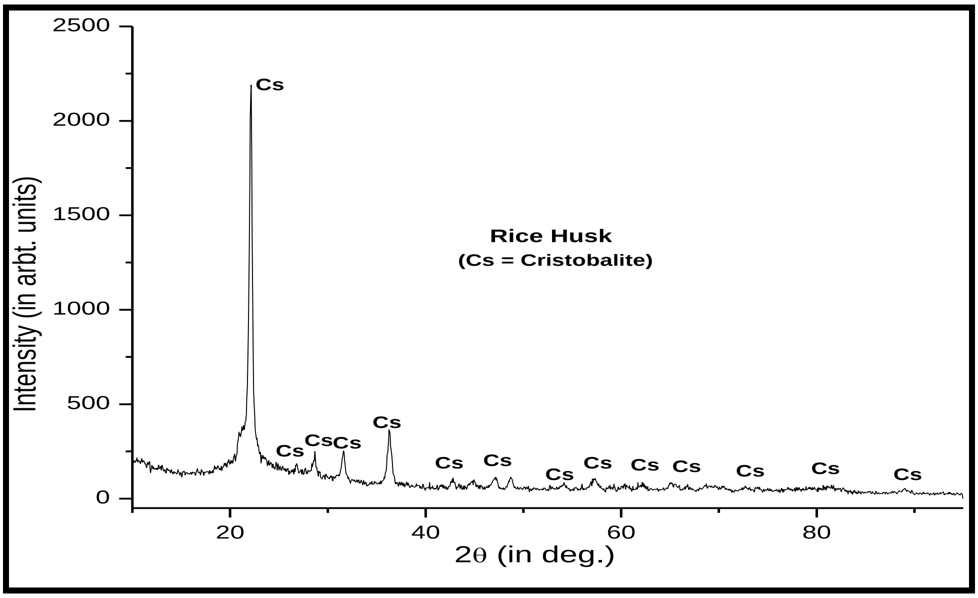

Fig. 3. *X-ray Diffraction (XRD) Pattern of the RHA Sample.*

The main constituent present in the RHA is Silica. The addition of RHA increases the amount of Silica in soil, which increases the strength and stability of soil sample. After addition of rice husk (RHA) with the soil, extra Cristobalite phase is obtained with the existing phases as shown in Figure 3.

METHODOLOGY AND TEST PROGRAMME[6–8]

All the tests of soil before and after stabilization with rice husk ash (RHA) and lime mixed in suitable proportions are carried out as per the procedures recommended in the relevant IS codes. For laboratory tests specimens of soil with and without admixtures were prepared by thorough mixing the required quantity of soil and stabilizers in pre-selected proportions in dry state and then required quantity of water was added and mixed thoroughly to get a homogeneous and uniform mixture of soil and admixtures. The California Bearing Ratio (CBR) tests were performed under soaked and unsoaked conditions for the original soil at the optimum moisture content (OMC).

Then the soil was mixed with the lime in proportion of 2%, 4%, 6%, 8% and 10% and California Bearing Ratio (CBR) tests were performed on the amended soil in the same manner. To study the effect of rice husk ash (RHA) with the addition of original soil in the proportion of 3%, 6%, 9% and 12% similar tests were also performed under the above conditions. After that the soil was mixed with different proportions of lime and rice husk ash (RHA). The combinations were taken from the above mentioned ranges for respective admixtures. The details of mix proportions are presented in Table 4 and all the tests were carried out on each mix as per the test program presented in Table 5.

Table 4. *Soil-Lime-RHA Mixes.*

S No.	Soil (%)	Lime (%)	RHA (%)	Remarks
1	100	0	0	Only Soil
2	98	2	0	Soil-Lime Mixes
3	96	4	0	
4	94	6	0	
5	92	8	0	
6	90	10	0	
7	97	0	3	Soil-RHA Mixes
8	94	0	6	
9	91	0	9	
10	88	0	12	
11	95	2	3	Soil-Lime-RHA Mixes
12	92	2	6	
13	89	2	9	
14	86	2	12	
15	93	4	3	
16	90	4	6	
17	87	4	9	
18	84	4	12	
19	91	6	3	
20	88	6	6	
21	85	6	9	
22	82	6	12	
23	89	8	3	
24	86	8	6	
25	83	8	9	
26	80	8	12	
27	87	10	3	
28	84	10	6	
29	81	10	9	
30	78	10	12	

Table 5. *Test Programme.*

Test programme	No of tests
Atterberg Limits (LL, PL)	30
Standard Proctor Test (MDD, OMC)	30
CBR Test at OMC (Soaked and unsoaked condition)	30
UCS Test(with curing period up to 180 days)	210

Preparation of Sample

The soil sample collected from the site was oven dried and sieved through 2.36 mm IS sieve and then it was dried in an oven at 105°C for 24 hours. The processing of RHA was done in a similar manner as that of soil. To mix the rice husk ash and lime with soil, the required quantity of sieved, oven dried soil was first weighed and poured into a mechanical mixture. Then the required quantity of lime and RHA, as required, was added to the soil and mixed uniformly. Proper care was taken to ensure uniform mixture of soil-lime-RHA. The sample of original and amended soil were tested as per the test programme (Table 5). All the tests were done following relevant IS codes (IS: 2720part 3–16).

RESULTS AND DISCUSSIONS

Liquid Limit (LL), Plastic Limit (PL) and Plasticity Index (PI)

When only lime is added liquid limit decreases with increasing lime percentage and plastic limit increases decreasing plasticity index. When only RHA is added liquid limit and plastic limit both increase but not appreciably and plasticity index almost remains in the range of that of original soil although effect of plasticity index is much pronounced when RHA content is as high as 12%.[9] When lime and RHA are added in combination their combined effect decreases the plasticity index indicating an expectation of better strength which is justified later. This effect is due to chemical action of lime and also the pozzolanic action of RHA. The variation of liquid limit, plastic limit and plasticity index respectively with percentage of lime for different RHA content are presented in Figure 4, Figure 5 & Figure 6.

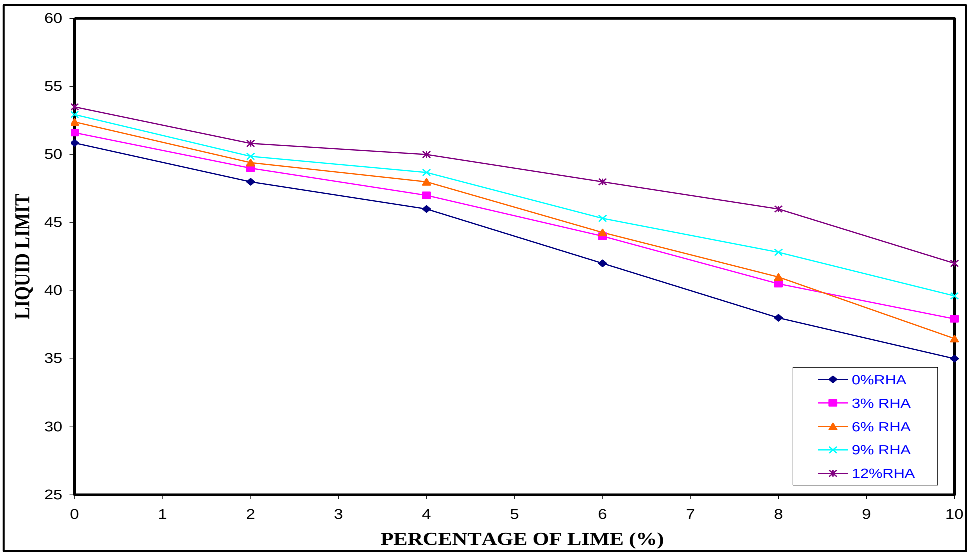

Fig. 4. *Variation of Liquid Limit with Lime Content for Different RHA Contents.*

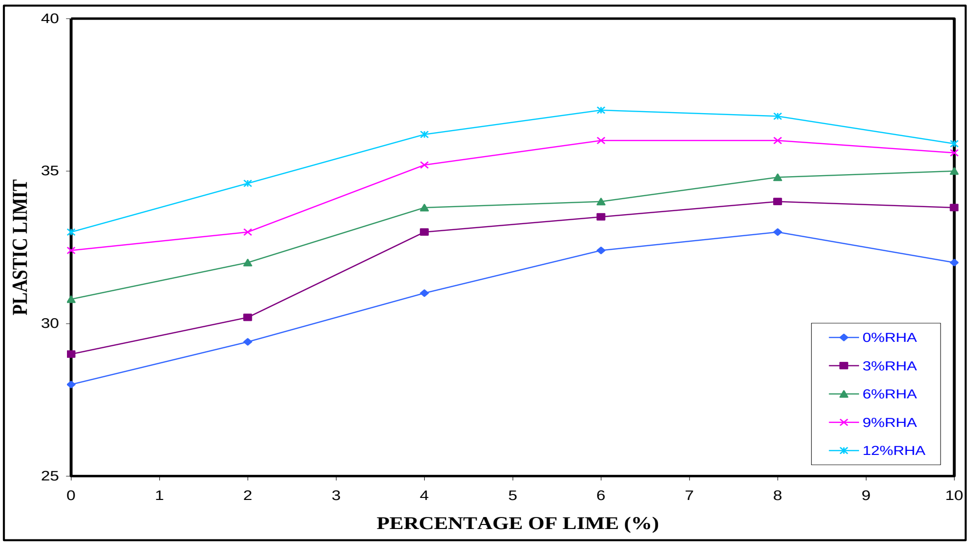

Fig. 5. *Variation of Plastic Limit with Lime Content for Different RHA Contents.*

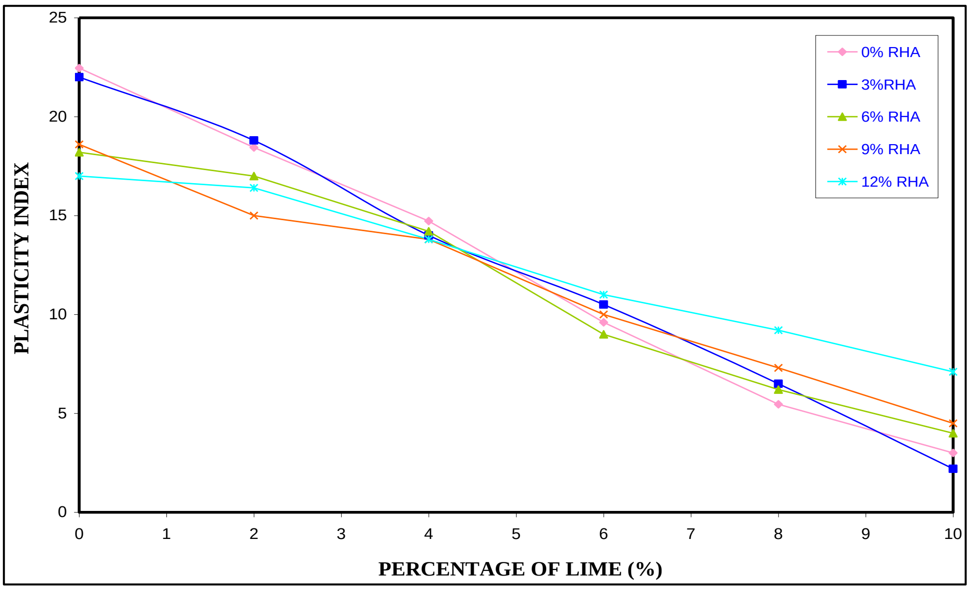

Fig. 6. *Variation of Plasticity Index with Lime Content for Different RHA Contents.*

Maximum Dry Density (MDD)

The variations of maximum dry density (MDD) with the different percentages of lime and rice husk ash (RHA) combinations are shown in Figure 7. The maximum dry density (MDD) generally decreases with increasing lime content. From Figure 7, it can be seen that maximum dry density (MDD) continues to decrease with increase in lime content for a given rice husk ash (RHA) content This is due to the flocculation and agglomeration of clay particles caused by cation exchange reaction leading to corresponding decrease in dry density. The decrease in MDD of the lime treated soil is reflection of the increased resistance offered by the flocculated soil structure to the compactive effort.[10]

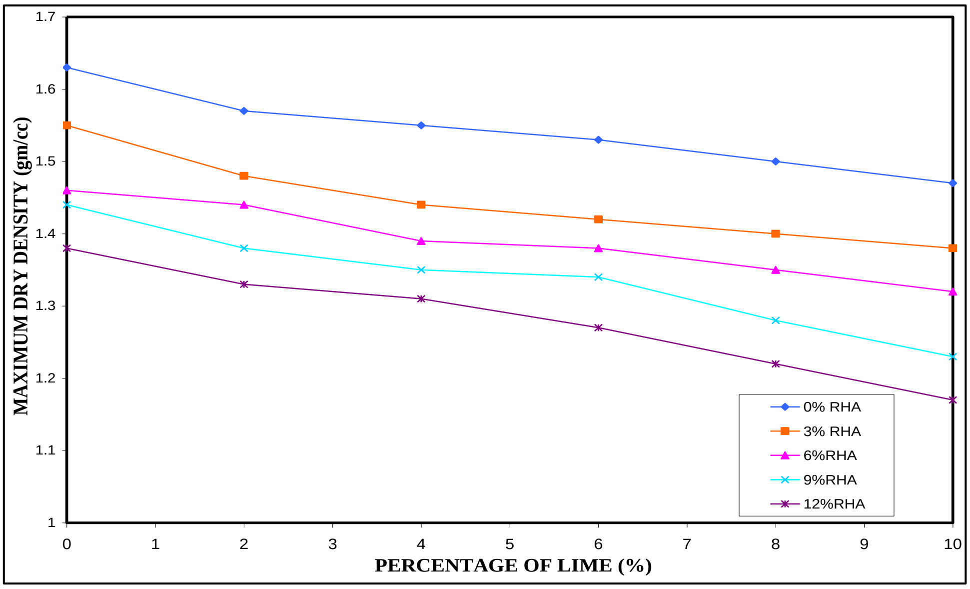

Fig. 7. *Variation of Maximum Dry Density with Lime content for Different RHA Contents.*

Optimum Moisture Content (OMC)

The results of the optimum moisture content (OMC) for soil-lime and rice husk ash combinations with different percentages are illustrated in the Figure 8. Generally the optimum moisture content

(OMC) increases with increasing lime content up to 6% and then decreases. The increase in optimum moisture content (OMC) in spite of the reduced the surface area is caused by flocculation and agglomeration, which is due to the additional fine contents requiring more water in addition to the free lime that needs more water for the pozzolanic reactions.[10]

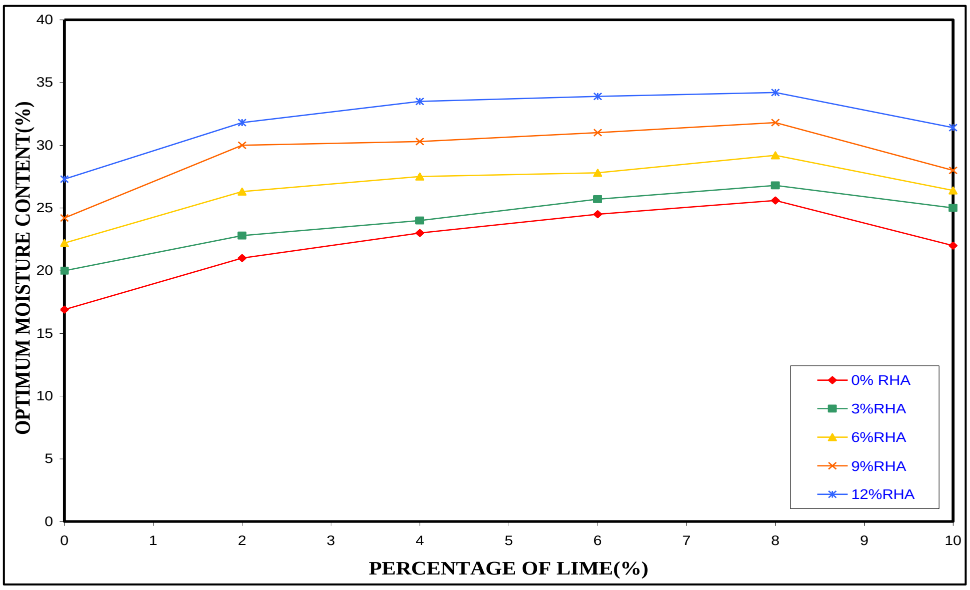

Fig. 8. *Variation of Optimum Moisture Content with Lime Content for Different RHA Contents.*

California Bearing Ratio (CBR) at OMC

The variations of California Bearing Ratio (CBR) with different percentage of soil lime and rice husk ash combinations at the optimum moisture content are presented in Fig. 9 and Fig. 10 for unsoaked and soaked conditions respectively. This plots show that the California Bearing Ratio (CBR) value increases with increase of lime content, as well as with increase of rice husk ash (RHA) content, when mixed individually and also in combination with the original soil. The maximum California Bearing Ratio (CBR) value at OMC of 28.25% is found to occur with the combination of 6% of lime and 9% rice husk ash (RHA) contents under un-soaked condition and the maximum value increases to 29.82% for 6% of lime and 6% rice husk ash (RHA) combination under soaked condition. The California Bearing Ratio (CBR) value is found to increase appreciably with addition of rice husk ash (RHA) at lower lime content when compared with the original soil. This is probably due to the chemical action of lime.[12]

In all the cases of soil lime and RHA combinations, the soaked CBR value is more than the unsoaked CBR. The increase in CBR value with the addition of lime is due to the formation of various cementing agents due to pozzolanic reaction between the amorphous silica or alumina present in natural soil and lime. This reaction produces stable calcium silicate hydrates and calcium aluminates hydrates as the calcium from the lime reacts with the aluminates and silicates of the soil.

It is also observed that when RHA is added to the original soil the strength characteristics also goes on increasing at a slower rate than for lime mixed soil. The soaked CBR value increases with the increase in RHA content at a higher rate than unsoaked CBR. The decrease in the rate of increase of CBR after 9% of RHA content at OMC may be due to the excess RHA which was not mobilized in the reaction as the presence of naturally occurring CaOH in soil may be small. The excess RHA occupies space within the specimen and reduces the clay and silt content in soil which reduces the cohesion in the soil RHA mixture.

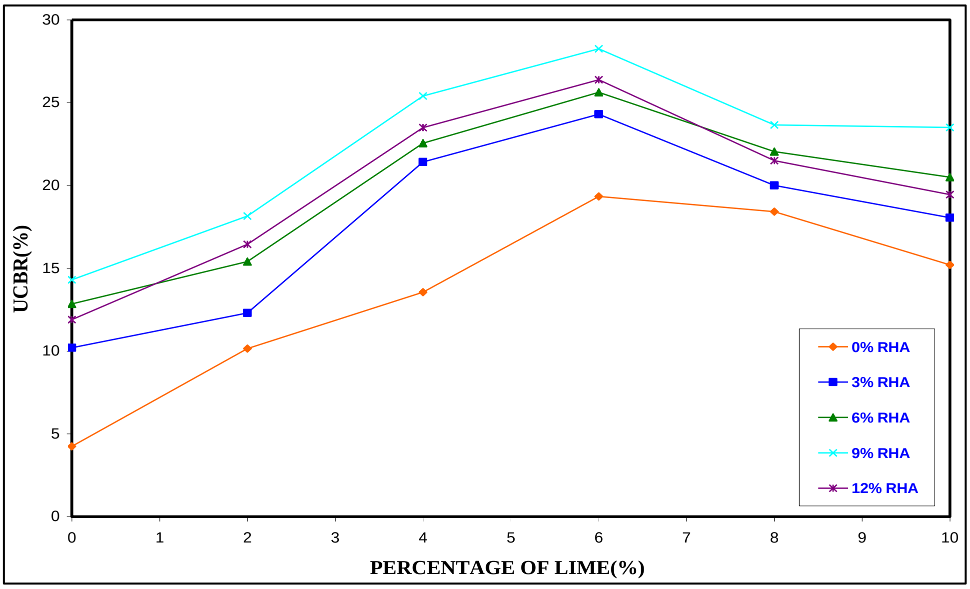

Fig. 9. *Variation of California Bearing Ratio with Lime and RHA Combinations in Unsoaked Condition at Optimum Moisture Content.*

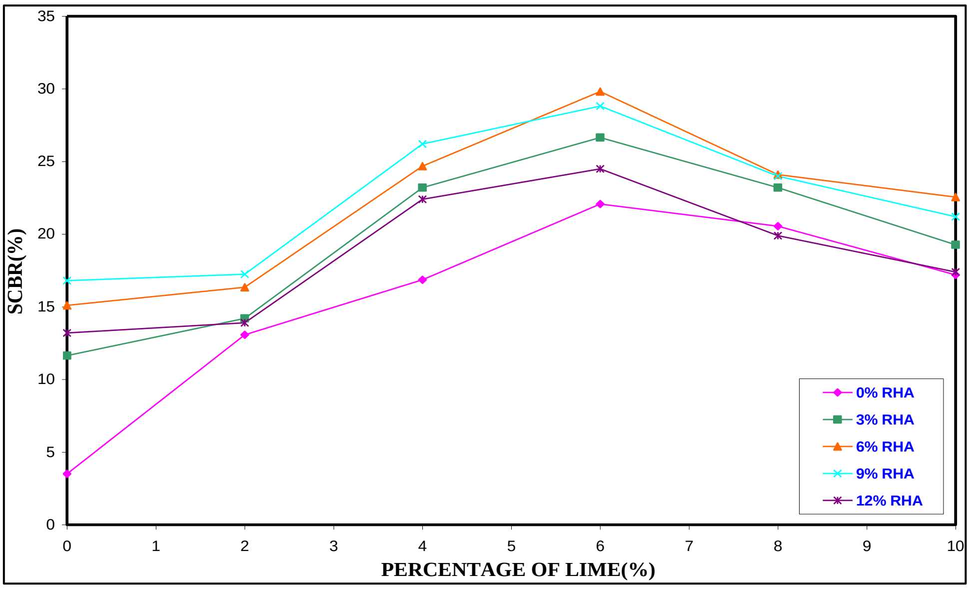

Fig. 10. *Variation of California Bearing Ratio with Lime and RHA Combinations in Soaked Condition at Optimum Moisture Content.*

Unconfined Compressive Strength (UCS) With Curing Effects

The Unconfined compressive strength (UCS) is the most common and acceptable method for determining the strength characteristics of soil. The variation of unconfined compressive strength (UCS) with the increase of lime content and rice husk ash (RHA) content separately and in combination over a curing period upto 180 days are shown in Figure 11–16 respectively.[11] In general the UCS values of soil-lime mixture increase with the increase of lime content and also with the curing period. The gain in strength of lime stabilized soil is primarily the pozzolanic reaction between silica and alumina present in natural soil and lime to form various cementing agents.

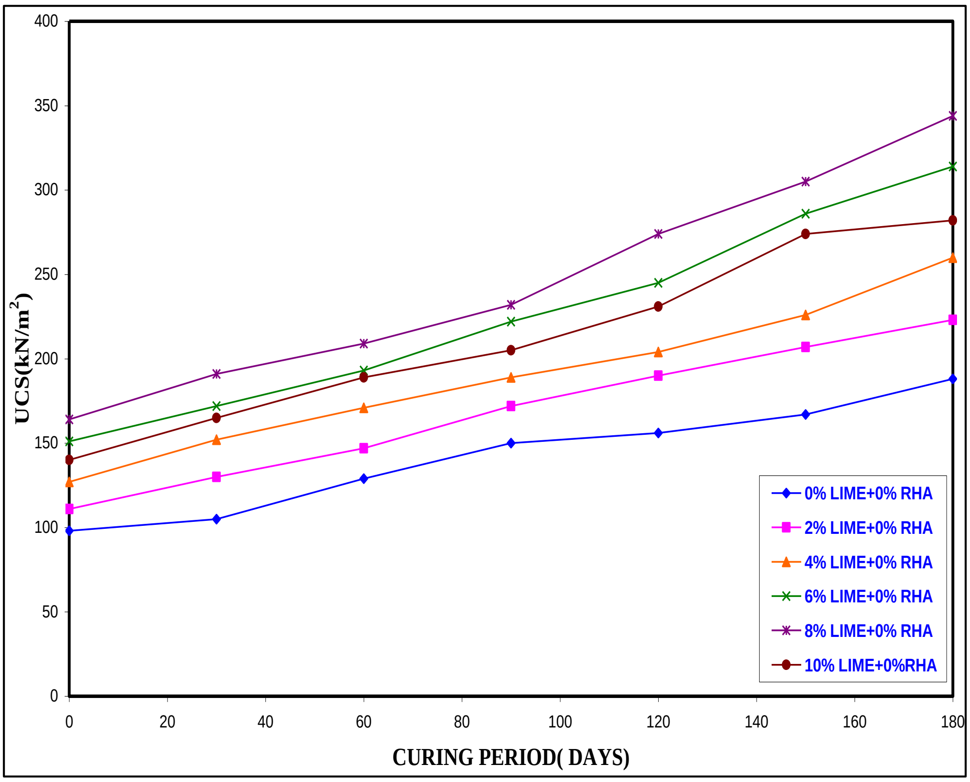

Fig. 11. *Variation of UCS with Lime with a curing period up to 180 Days.*

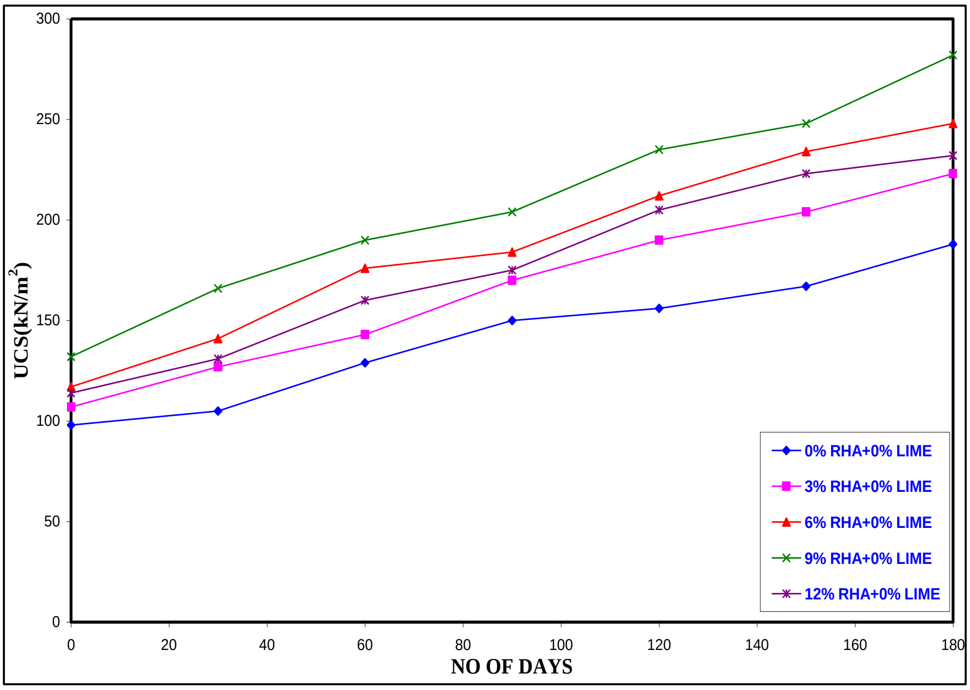

Fig. 12. *Variation of UCS with RHA with a Curing Period up to 180 Days.*

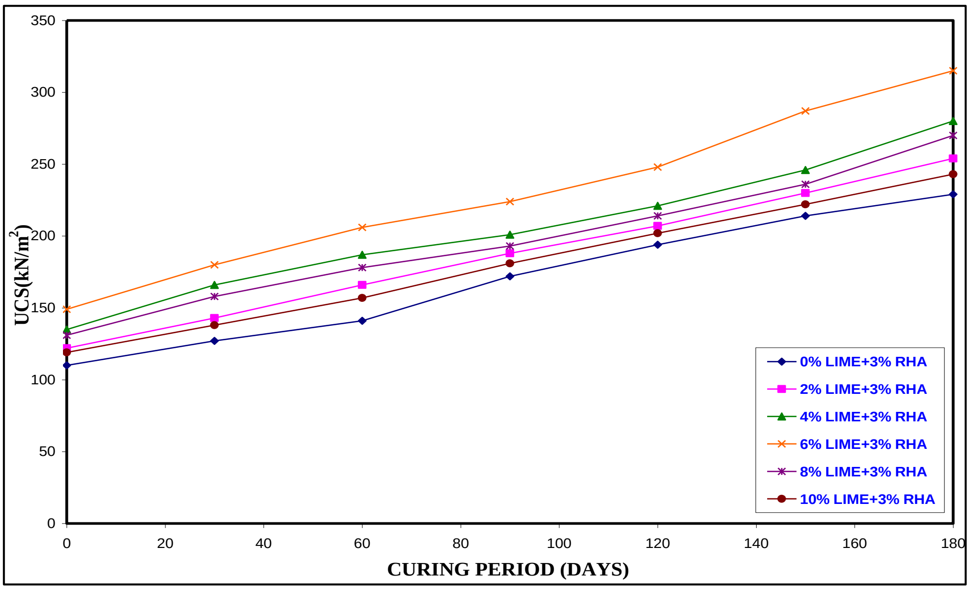

Fig.13. *Variation of UCS with Lime and 3% of RHA with a Curing Period up to 180 Days.*

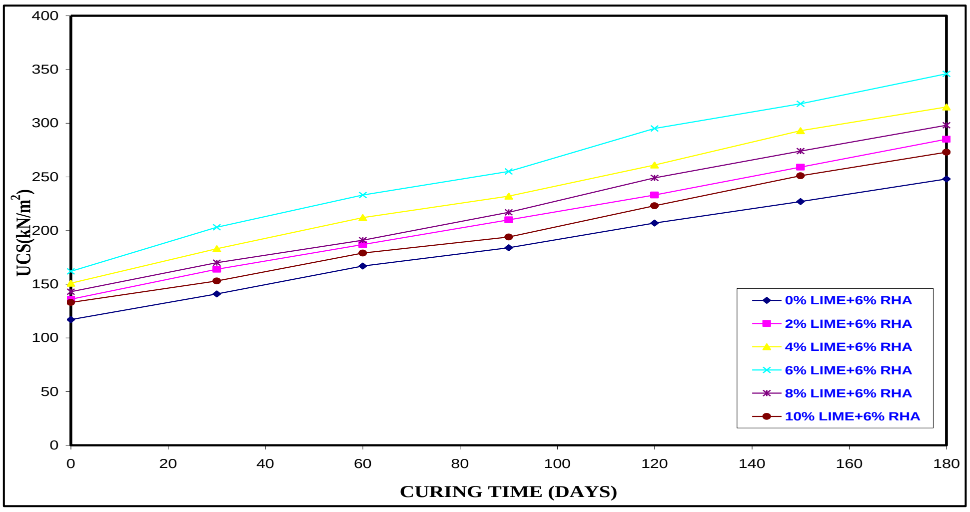

Fig.14. *Variation of UCS with Lime and 6% of RHA with a Curing Period up to 180 Days.*

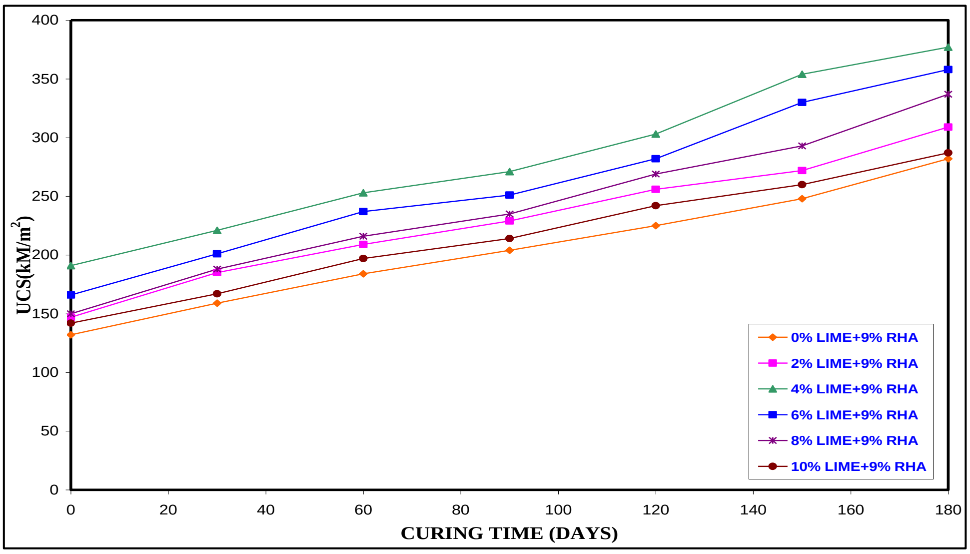

Fig.15. *Variation of UCS with Lime and 9% of RHA with a Curing Period up to 180 Days.*

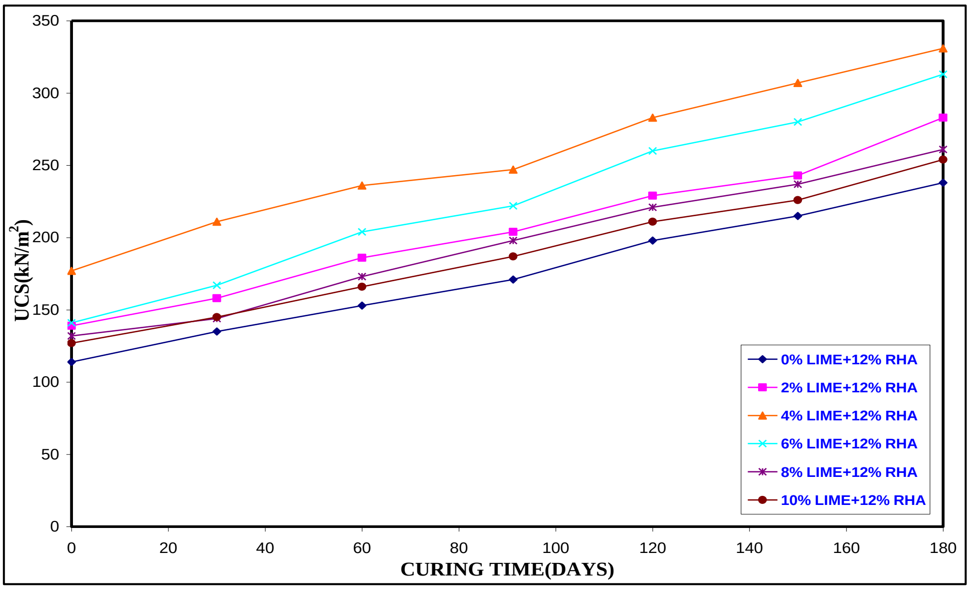

Fig.16. *Variation of UCS with Lime and 12% of RHA with a Curing Period up to 180 Days.*

From the Figure 11 and Figure 12, it is observed that the unconfined compressive strength (UCS) value increases with the curing period for a fixed lime and rice husk ash (RHA) content, up to 9% of rice husk ash (RHA) and 8% of lime individually. Beyond these limiting values the unconfined compressive strength (UCS) decreases. The general trend in change in unconfined compressive strength (UCS) value is more in when lime is added.

From graphs shown in Figure 13 and Figure 16, it is observed that at 3–6% of RHA and 6% lime mixes the maximum UCS value has been achieved as 346 kN/m^2, but increase of RHA content further to 9% and even upto 12% a higher UCS value of 377 kN/m^2 is achieved with only 4% of lime content. This is due to the fact that addition of RHA makes the use of admixture cost effective.

The improvement in respect of the curing period with addition of lime and rice husk ash (RHA) and their combined effects is presented in Table 6.

Table 6. *Percentage Improvement of UCS (With Respect to Original Soil).*

Admixture	Unconfined compressive strength (kN/m^2)		Percentage of improvement **(%)
	0 Day	180 Days	
100% Soil + 0% Lime + 0% RHA	98	223	127
92% Soil + 8% Lime + 0% RHA	164	344	251
91% Soil + 0% Lime + 9% RHA	132	282	188
91% Soil + 6% Lime + 3% RHA	149	315	221
88% Soil + 6% Lime + 6% RHA	162	346	253
87% Soil + 4% Lime + 9% RHA	191	377	285
84% Soil + 4% Lime + 12% RHA	177	331	238

**With respect to the original soil [UCS = 98 kN/m^2]

It appears from this table, that unconfined compressive strength (UCS) improved by 127% for ordinary soil, but when with the addition of 8% lime it is improves by 251% and addition of 9% rice husk ash (RHA) it improves by 188%. The effect of lime is more predominant during curing and this is due to chemical action of lime.

In case of rice husk ash (RHA) the pozzolanic action is not so predominant and it is of a little lesser degree.

It further appears from Fig.15 that maximum strength improvement occurs for 9% rice husk ash (RHA) and 4% lime is sufficient to get the maximum strength with curing time of 180 days i.e. 285%. This is due to the enhanced supply of silica by RHA for reaction with lime. From the table it further appears that as the percentage of rice husk ash (RHA) increases the percentage of lime required to achieve the maximum strength decreases. This indicates that with a little addition of rice husk ash (RHA) the requirement of lime content becomes less for achieving the maximum strength. This can make the mixture maximum cost effective, because the rice husk ash (RHA) is cheap and easily available compared to lime.

STATISTICAL ANALYSIS

A statistical analysis has been developed with the help of Multiple Regression Analysis to obtained correlations of CBR with the index properties and compaction characteristics of soil at optimum moisture content under soaked and unsoaked conditions. The analysis has been carried out by using standard statistical software like Stat-Plus 2009 by inputting the laboratory test data are obtained. The validity of the correlation was established with R2 values. The details of equation with different statistical parameters are presented below

$$UCBR(OMC) = 6.09LL - 2.92PL - 6.18PI + 19.16MDD - 0.29OMC - 105.52$$
……..i)

Model Summery

R	R^2	Adjusted R^2	Standard Error
0.91	0.83	0.79	2.58

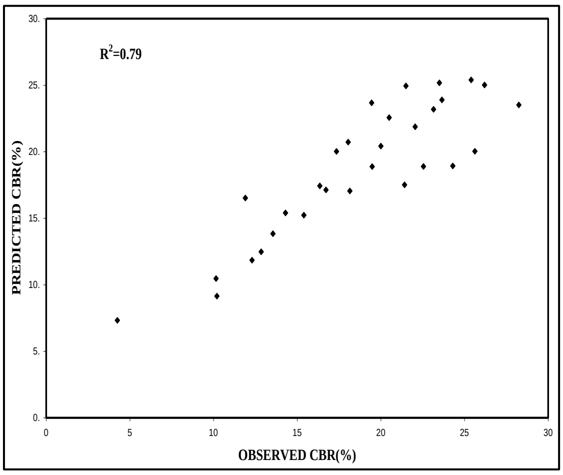

Fig.17. *Scatter Diagram of Predicted CBR and Observed CBR at OMC (Unsoaked).*

$$SCBR\ (OMC) = 7.12\ LL - 3.97\ PL - 7.38\ PI - 22.65\ MDD - 0.62\ OMC - 97.24$$
………ii)

Model Summery

R	R^2	Adjusted R2	Standard Error
0.84	0.71	0.66	3.41

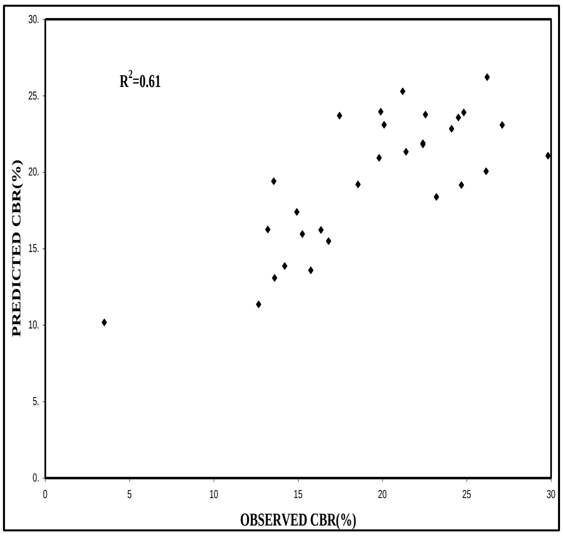

Fig.18. *Scatter Diagram of Predicted CBR and Observed CBR at OMC (Soaked).*

The above correlations can predict the CBR values at the optimum moisture content under soaked and unsoaked conditions from the index properties and compaction characteristics of soil within reasonable limits of errors. Based on the equations, scatter diagram of predicted CBR and observed CBR at OMC under unsoaked and soaked conditions are presented in Fig. 17 and Fig. 18 respectively. The values of R^2 for the both equation are nearly closed to unity. The values of standard error are more, if the curing time of CBR is more i.e in soaked condition.

SEMIQUANTATIVE ANALYSIS

An attempt has been made to carry out semi quantative analysis in terms of XRD and XRF of a few selected mixes of soil, lime and rice husk ash. The higher and lower values of CBR are the selection criteria of sample for carrying out these tests. This has been done to interpret the reason of change of CBR value in the compositional matrix of the mix.

The X-ray diffraction (XRD) patterns of the used soil sample shows that the starting soil sample contains crystalline quartz, mica and clinochlore. It appears from the Table 6 that the addition of RHA increases the amount of Silica in soil, which increases the strength and stability of soil sample. After addition of rice husk (RHA) with the soil, extra Cristobalite phase is obtained with the existing phases. The details of phases with the addition of admixtures are presented in the Table: 6.The chemical composition of the soil and others investigated samples have been examined by X-Ray Fluorescence (XRF) spectrum are presented in Table 7.

Table 7. *Weight Percentage of Phases as Obtained by Rietveld Analysis.*

Sample marks	Phase identification from XRD	Weight percentage
Soil 100%	Quartz	43.3
	Mica	47.8
	Clinochlore	8.9
Soil + 3% RHA	Quartz	43.7
	Mica	38.5
	Clinochlore	8.6
	Cristobalite	9.2
Soil + 9% RHA	Quartz	33.5
	Mica	39.9
	Clinochlore	15.4
	Cristobalite	11.2
Soil + 2% Lime + 3% RHA	Quartz	39.4
	Mica	35.2
	Clinochlore	13.6
	Cristobalite	3.7
	Gismondine	8.1
Soil + 8% Lime + 3% RHA	Quartz	50.6
	Mica	35.2
	Clinochlore	11.7
	Cristobalite	1
	Gismondine	1.4
Soil + 2% Lime + 9% RHA	Quartz	39.2
	Mica	33.7
	Clinochlore	13.5
	Cristobalite	5
	Gismondine	8.7
Soil + 8% Lime + 9% RHA	Quartz	45
	Mica	29.3
	Clinochlore	12.8
	Cristobalite	3.5
	Gismondine	9.3

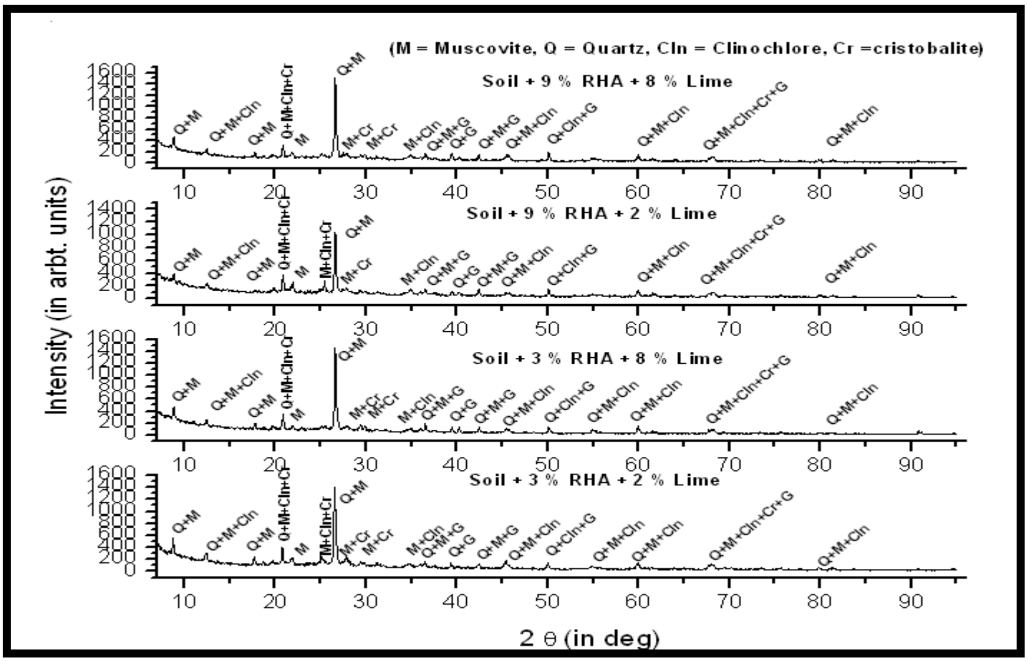

Fig. 19. *X-ray Diffraction (XRD) Pattern of Soil-Lime-RHA Combinations.*

The XRD patterns of the Soil-Lime-RHA mix in different proportions are shown in Figure 19.

Observations from XRD/XRF Analysis

It is observed from Table 7, that weight percentage of cristobalite phase increase with increase of rice husk ash percentages and weight percentage of mica decreases with that. The observed soaking strength is around 16.8% when the soil mixed with 9% RHA. Increase of strength may be due to the reduction of Mica in the soil sample. Hence the increase of silica in the soil sample finally increases the strength and stability of soil sample. XRF results also corroborates with this results (Table 8). It is also observed that maximum soaking strength for these combinations is around 24.82% for the soil mixed with 9% RHA and 8% lime content. It is obvious because the percentage weight of mica phase becomes minimum for this composition.

From XRF results (Table 8) it is also observed that silica and calcium contents are maximum for this composition. Hence, XRD and XRF results reveal that the mica phase play very important role for maintaining the strength and stability of the soil samples.

Table 8. *Semi-Quantitative Elemental Analysis of the Investigated Samples from XRF.*

Compound Name	Sample Designations							
	Soil 100%	Lime	Soil +3% RHA	Soil +9% RHA	Soil +3% RHA +2% Lime	Soil +3% RHA +8% Lime	Soil +9% RHA +2% Lime	Soil +9% RHA +8% Lime
SiO_2	59.113	38.271	59.187	59.528	59.193	58.549	58.819	59.261
Al_2O_3	21.358	-	20.596	18.496	20.519	19.534	19.515	19.23
Fe_2O_3	9.136	0.189	9.45	10.276	9.181	8.71	9.02	8.236
CaO	1.601	57.857	1.794	2.103	2.478	5.039	3.107	5.139
K_2O	3.582	0.065	3.499	3.71	3.49	3.279	3.415	3.281
MgO	2.96	0.643	2.923	2.698	2.628	2.609	2.616	2.542
TiO_2	1.047	0.026	1.011	1.092	1.037	0.985	1.001	0.936
Na_2O	0.705	0.076	0.696	0.694	0.73	0.737	0.804	0.734
P_2O_5	0.107	-	0.136	0.19	0.153	0.119	0.148	0.441
SO_2	0.295	2.873	0.605	1.084	0.492	0.347	1.449	0.1
MnO	0.095	-	0.105	0.128	0.099	0.093	0.105	0.1

CONCLUSION

The following conclusions may be drawn from the present investigation

1. The treatment of soil with addition of admixtures such as lime and RHA has a general trend of decrease in liquid limit and increase in plastic limit and decrease of plasticity index.
2. The liquid limit decreases for all soil-lime-rice husk ash combinations and the stabilized soils appear to be suitable for construction as pavement materials for the flexible pavements as is seen from CBR values.
3. In general the plastic limit increases with the increase in lime percentage as well as rice husk ash content and up to 6% and 12% lime and RHA contents respectively. Beyond these limits it is more or less constant or shows slightly decreasing trend for all cases.
4. The addition of admixtures with the soft sub-grade decreases the Maximum Dry Density and increases the Optimum Moisture content. The maximum dry density is generally reduced with the increase in lime and rice husk ash contents both separately for all cases.
5. The optimum moisture content increases with increasing lime content up to 6% and RHA content up to 12% and then decreases.
6. The strength characteristics in terms of CBR value is found to increase appreciably with addition of RHA at lower lime content when compared to the original soil. This is due to the pozzolanic action of lime and RHA.
7. Soil, when mixed with lime and RHA combinations the CBR values increase appreciably both under soaked and un-soaked conditions.
8. The maximum CBR value of 28.25% is found to occur with the combination of 6% of lime and 9% RHA contents under un-soaked condition and this value increases up to 29.82% for 6% of lime and 6% RHA combination under soaked condition at the optimum moisture content.
9. The curing period has the influence on the UCS value of admixture contained soil. The UCS value increases with the curing period for a fixed lime and RHA content, upto 9% of RHA and 8% of lime individually and beyond these limiting values the unconfined compressive strength decreases.
10. It may be inferred that at 3%–6% of RHA and 6% lime mixes the maximum UCS value is achieved as 346kN/m^2, but increase of RHA content further to 9% even upto 12% the higher UCS value is achieved as 377 kN/m2 with only 4% of lime content which may lead to cost effective construction.
11. The maximum increase in UCS by 285% with the addition of 4% lime and 9% RHA and which appears to be the maximum degree of improvement with lime and RHA respectively over a curing period of 180 days. This is due to the enhanced supply of silica from RHA for reaction with lime.
12. A correlations have been derived that can predict the CBR values in soaked and unsoaked conditions from the index properties and compaction characteristics of soil within reasonable limits of errors.
13. XRD and XRF results reveal that the mica phase and silica and calcium content play very important role for maintaining the strength and stability of the soil samples.

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