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Influence of Compaction Moisture Content on UCS and CBR of RHA-Lime Stabilized BC Soil

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Introduction

Annual production of paddy in India is about 100 million tonnes which gives about 20 million tones of rice husk (20 % of paddy). Rice husk is mostly used as a feed in the boiler for processing paddy and producing energy through direct combustion and / or by gasification. Burning the rice husk generates about 22% of its weight as ash. Therefore huge quantities of rice husk ash, more than 4 million tonnes producing annually in India. Unless properly disposed off, accumulation of rice husk and/or rice husk ash poses several environmental disposal problems.

Studies have shown that RHA is used to produce special cement and concrete, low cost building materials, etc. (Cook, 1986., Rao et al., 1999., Seehra et al., 1998). Recent research, based on super pozzolanic activity, has proved that RHA is a potential material to be utilized for improving soil properties. RHA can not be used alone for the stabilisation of soil due to absence of cementitious properties. Bhasin et al., (1988) have showed UCS of BC soil got influenced by RHA and lime sludge and maximum strength attained in case of soil with the combination of RHA and lime sludge than with RHA alone. Jawaid et al., (1996) have reported that the influence of RHA with gypsum on shearing strength of silty sand. 4% rice husk ash and 8% gypsum are the optimum binders and beyond this mix proportions strength decreased due to unused portion of stabilizers.

The design, construction and performance of pavement are relative to the movement of moisture, its accumulation, and prediction and control of sub base moisture content. Stabilisation of clayey soil with lime-RHA is more advantageous when moisture content of the soil in the field is high (Muntohar et al., 2002). It is established that use of RHA between 10 to 12.5% and lime between 5 to 8% improves properties of clayey soil. The development of strength of stabilised soils depends primarily on the chemical reaction products and reaction rate during stabilisation proceeding, and the chemical reaction products and reaction rate are related to the relative elements or ions from stabilizer and soil (Masashi et al., 1999). It is believed that strength of compacted clay increased with lime addition and it is more significant due to curing. Water during curing brings out the clay particles bridging bond themselves (Asavapisit et al., 2003). The initial water content affects the

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compressive strength of lime treated soils since water provides pozzolanic reaction between lime and soil chemical elements (Locat et al. 1990). Moisture content and development of strength with age has been well recognized and hence critical moisture content at which strength of stabilised soil attained maximum is the correct parameter to evaluate for design purpose (Babu et al., 2002). In the present study an attempt is made to evaluate the critical compaction moisture content at which RHA-lime stabilized BC soil exhibit higher unconfined compressive strength and California Bearing Ratio.

Materials and Methods

Materials

BC soil used in this study was extracted at depth 1.0m from ground level in Chikmagalur, Karnataka, India. The BC soil was air-dried pulverized, mixed thoroughly and stored in airtight containers. A clean dust free rice husk was procured from local rice mill and burned in a tube in basket rice husk burner. The RHA is fine-grained, gray in colour and high pozzolanic in nature. The properties of BC soil and RHA as determined in the laboratory are given in Table 1. Commercially available lime in powdered form was used for the lime treatment. Chemical compositions of materials used are given in Table 2.

Table 1 Physical Properties of BC Soil and RHA Used

Properties	***BC Soil***	***RHA***
Specific gravity	2.67	1.92
Liquid limit (%)	64.9	128.5
Plastic limit (%)	28.9	Non plastic
Shrinkage limit (%)	11.5	-
Plasticity index (%)	36.0	-
Gravel size fraction (%)	-	-
Coarse sand size fraction (%)	1.5	-
Medium sand size fraction (%)	4.0	2.84
Fine sand size fraction (%)	12.54	31.45
Silt size fraction (%)	26.0	52.35
Clay size fraction (%)	55.96	13.36
Maximum dry density (kN/m^3)	14.75	7.09
Optimum moisture content (%)	26.53	74.24
Free swell index (%)	109.12	-

Testing Methods

Consistency limits tests were conducted as per IS 2720 (part 5) (BIS, 1985). Mixing proportion was considered by varying RHA content from 5% to 15% in steps of 5% and lime content from 2% to 10% in steps of 2% by weight of soil. Standard proctor tests were conducted in accordance with IS 2720 (part 7) (BIS, 1980). The guidance on proportioning lime of 6 % by weight with different BC soil –RHA combinations, in determining compaction properties is based on earlier studies.

Table 2 Chemical Composition of Materials Used

Elements	*BC Soil %)*	*RHA (%)*	*Lime (%)*
SiO_2	38.32	83.32	4.71
Fe_2O_3	2.69	0.8	0.395
SO_3	0.034	-	0.77
CaO	3.05	0.71	80.06
MgO	2.69	-	1.12
Al_2O_3	5.93	0.8	1.05
Ignition Loss	11.04	5.23	14.83
pH	8.06	9.69	12.54

For unconfined compressive strength tests cylindrical specimens of size 38mm diameter and 76mm height were prepared by compacting known quantity of sample material statically. The static compaction was carried out alternatively from both ends of a steel mould to ensure uniform compaction of the sample. Specimens of all combinations of BC soil-RHA-lime mixtures were compacted at their maximum dry density (MDD) with different moisture content i.e. at OMC, wet optimum side and dry optimum side. Moisture content beyond OMC is referred as moulding moisture content (MMC). Moulding moisture content on wet side optimum was increased in steps of 2% up to 8% and MMC on dry side optimum decreased in steps of 2% up to 4%. Specimens after demoulding were weighed and kept in desiccators for curing. The curing periods adopted were 3, 6, 13, and 27 days of moist curing and plus one day water immersion. During moist curing humidity and temperature were maintained without loss of any moisture content. After immersion period of one day, samples were tested under strain rate of 1.25 mm/minute. UCS tests were also conducted on specimens, immediately after removing from the mould.

Unsoaked and soaked CBR tests were conducted on standard mould in accordance with IS 2720 (BIS, 1979). CBR samples were compacted statically at (1) MDD with OMC and at (2) MDD with MMC = OMC+4% for all combinations of mixes except the mix soil+15%RHA+6%L, for which MMC = OMC+6%. MMC used in the preparation of CBR samples were corresponding to MMC at which UCS values are found maximum. To understand the effect of curing, standard procedure of curing, soaking and testing as followed. A Surcharge weight of 50 N was used during curing, soaking and testing. The curing periods adopted were immediate (4 days soaking), 7 days (3 days moist curing + 4 days soaking), 14 days (10 days moist curing + 4 days soaking) and 28 days (24 days moist curing + 4 days soaking). During moist curing samples with surcharge weight were kept covered under gunny bags. A metal penetration plunger of diameter 50 mm and 100 mm long was used to penetrate the samples at the rate of 1.25 mm/minute.

Results and Discussions

Atterberg's Limits

Figures 1, 2 and 3 show the effect of RHA and lime addition on consistency limits.

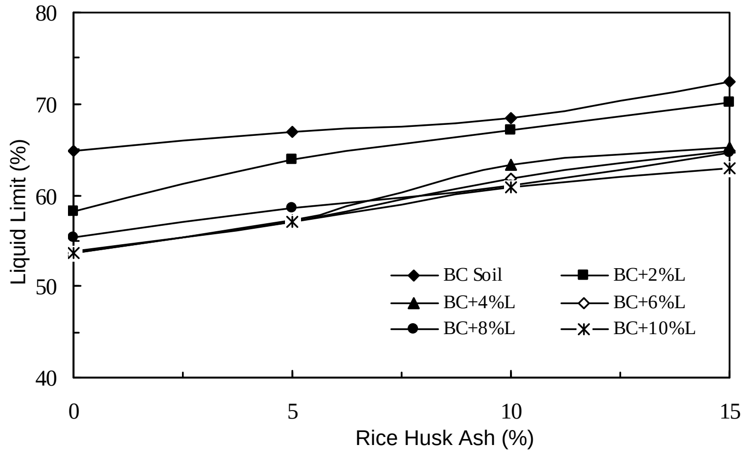

Fig. 1 Effect of RHA and Lime on Liquid Limit of BC Soil

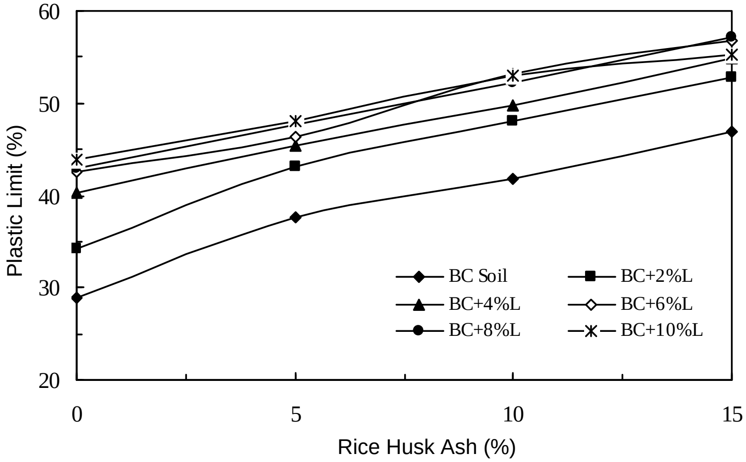

Fig. 2 Effect of RHA and Lime on Plastic Limit of BC Soil

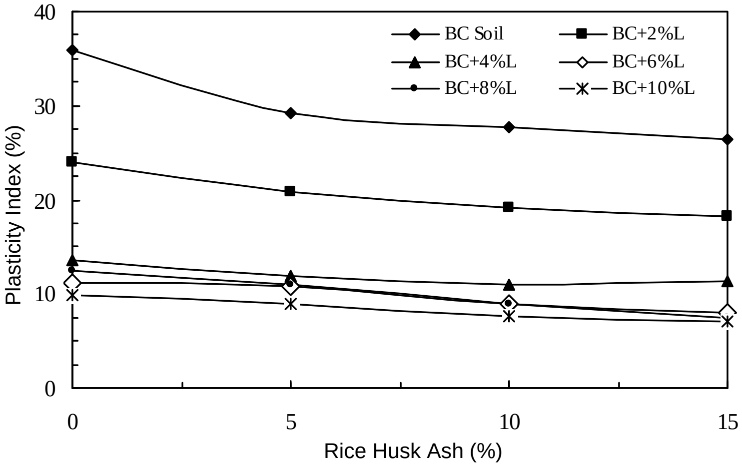

Fig. 3 Effect of RHA and Lime on Plasticity Index of BC Soil

Both LL and PL of BC soil increased on addition of RHA but, resulting PI of BC soil is less significant. It can be seen the decrease in the PI of BC soil is only 6 to 9% for RHA content between 5 to 15%. This indicates that, the matrix of BC soil is not affected significantly by RHA alone. The PI of BC soil and BC soil-RHA mixtures decreased significantly due to addition of lime. It is observed that the liquid limit of BC soil and BC soil-RHA mixtures decreased with increased plastic limit and the resulting PI values are reduced to higher percentages. Addition of lime decreases the liquid limit due to exchange of cat ion and chemical reaction among chemicals of soil, CaO of lime and SiO_2 of RHA. Therefore remarkable reduction in the plasticity index of BC soil and BC soil-RHA mixtures is observed. Lime addition to BC soil decreases the liquid limit immediately due to decreased diffused double layer thickness of clay particles (Sivapullaiah et al., (1996). Adding lime minimises the plasticity index of soil by converting soil in to the rigid or granular mass (Emhammed et al., 2002). The decrease in the PI of BC soil and BC soil-RHA mixtures increased up to lime content of 6% and beyond 6% the reduction of PI of mixtures are not significant. At 6% lime content, PI of BC soil is 36% reduces to 11.5 % and with RHA combinations PI of soil reduced further. Jawaid et al., (1990) and Muntohar et al., (2002) have established that the use of RHA between 10 to 12.5 % and lime between 5 to 8 %, improves the properties of clayey soils. Excess of lime reduces the strength and weakens the soil initial properties due to liberation of excess heat during hydration (Mukherjee, 1995). Therefore in this study, 6% lime is taken as optimum level of lime content for establishing the strength properties of BC sol with RHA.

Compaction Characteristics

The results of standard Proctor compaction tests on BC soil treated with RHA and lime are presented in Table 3. It is observed that, MDD of BC soil decreased with increased OMC values due to RHA content from 5 to 15%. This is due to low specific gravity of RHA and its porous nature. Up on adding 6% lime to BC soil-RHA mixtures MDD decreased further associated with increased

OMC. Lime reacts with SiO_2 of RHA and soil chemicals brings about the changes in base exchange, aggregation and flocculation resulting in increase in the void ratio of the mix which leads to decrease in the MDD value. Porous nature of RHA also affects the above changes and therefore BC soil-RHA-lime mixes requires lower compaction effort to reach their maximum dry density, which leads to lower compaction cost.

Table 3 Compaction Properties of BC Soil-RHA-Lime Mixes

Mix proportion (%)			***MDD (kN/m^3)***	***OMC (%)***
BC Soil	RHA	Lime		
100	0	0	14.75	26.53
0	100	0	7.09	74.24
95	5	0	14.08	29.15
90	10	0	13.78	30.55
85	15	0	13.34	32.48
94	0	6	14.26	28.35
89	5	6	13.73	32.84
84	10	6	13.52	33.64
79	15	6	12.94	36.48

Unconfined Compression Test Results

UCS of Soil Mixes with RHA and Lime at MDD with OMC

Results of UCS of soil stabilised with RHA and lime combinations compacted at MDD with OMC for different curing periods, are shown in Figure4.

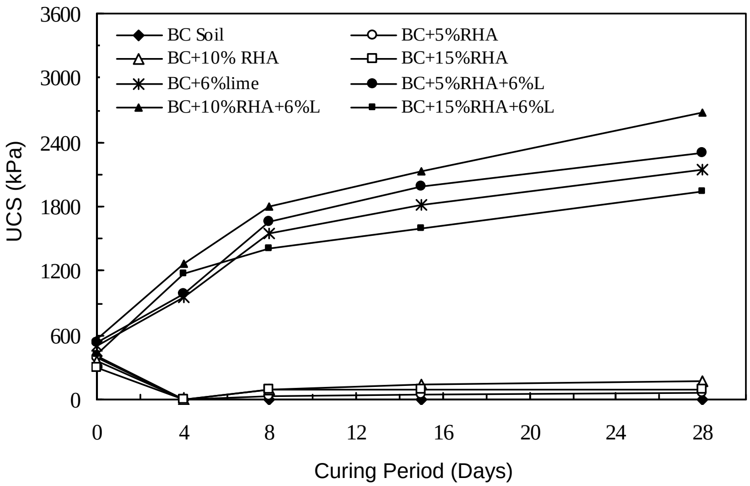

Fig. 4 Effect of Curing on UCS of BC Soil-RHA-Lime Mixes, Compacted @ MDD with OMC

Samples of BC soil and BC soil-RHA mixtures with no lime content showed zero or very less strength even samples are cured for 28 days. This is because, the absence of reacting agent lime. UCS of BC soil with fly ash content decreased continuously for all curing periods due to absence of free lime (Sridharan et al., 1997). On addition of lime to BC soil and BC soil-RHA mixtures, strength has increased with curing periods. Lime provides calcium for silica of RHA to solubilisation which increases the pozzolanic reaction to form more cementitious product with curing period and therefore higher strength is observed. It is believed that the cementing materials like calcium silicate hydrate (C-S-H) and calcium aluminate hydrate (C-A-H) formed during pozzolanic reaction between the soluble silica and alumina from clay and the residual free calcium from lime filled the voids space between the clay particles (Macallister and Perty, 1992). Strength of BC soil at 15% RHA with lime combination is found decreased. This is because of lower density of mixtures and due to unused portion of additives disturbs the matrix of mixtures. It can be seen the strength of mix BC soil+10%RHA+6%lime is higher than the strength of mix BC soil+15%RHA+6%lime at all levels of curing periods. Jawaid et al., (1996) reported decrease in the strength of soil due to increase in RHA and gypsum additives percentage beyond the limiting proportions is due to unused portion of the stabilizers, which preventing point to point contact of aggregate particles.

Effect of Moulding Moisture Content on UCS of Soil-RHA-Lime Mixes

Figures 5, 6, 7 and 8, show the influence of moulding moisture content beyond OMC both on wet and dry side of optimum on UCS of soil blended with different proportions of RHA with and without 6 % lime and cured for 4 days, 7 days, 14 days and 28 days, respectively. The UCS of BC soil treated with lime and RHA-lime mixtures increased with increase in moulding moisture content on wet side of optimum up to 4% except the mix BC soil+15%RHA+6%lime, for which UCS increased up to 6%.

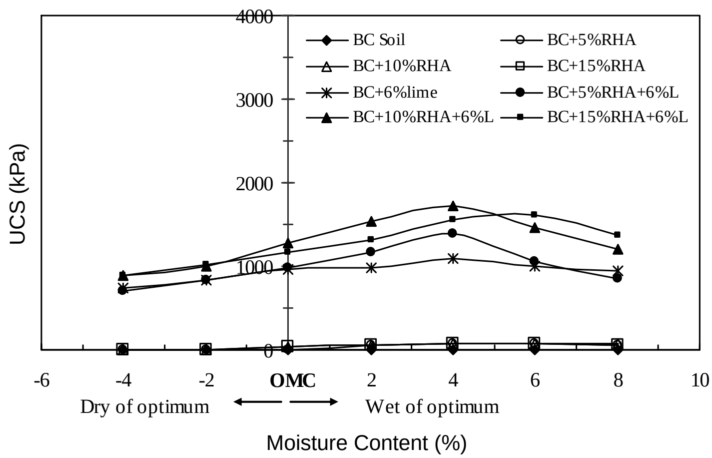

Fig. 5 Moisture Content Effect on UCS of BC Soil-RHA-Lime Mixes Cured for 4 Days

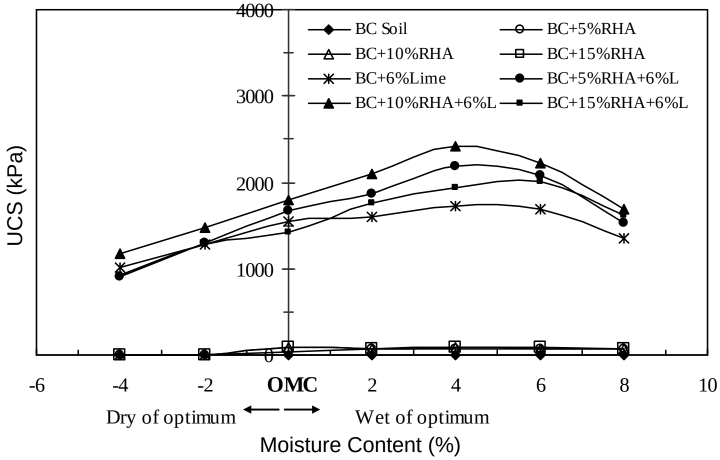

Fig. 6 Moisture Content Effect on UCS of BC Soil-RHA-Lime Mixes Cured for 7 Days

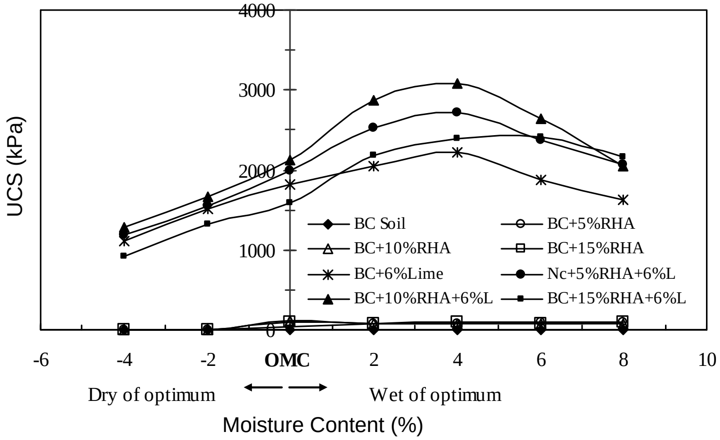

Fig. 7 Moisture Content Effect on UCS of BC Soil-RHA-Lime Mixes Cured for 14 Days

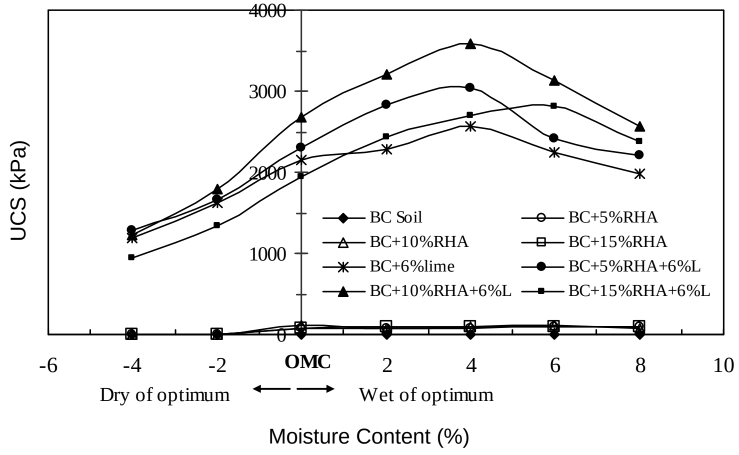

Fig. 8 Moisture Content Effect on UCS of BC Soil-RHA-Lime Mixes Cured for 28 Days

The additional water content beyond OMC on wet side of optimum used for pozzolanic reaction among chemicals of soil, RHA and lime during curing; bring the phenomenal of gain in strength. At higher MMC, decrease in UCS is observed because supplement of water beyond the limit of MMC during pozzolanic reactions leaves behind pores which are partly filled with cement like materials. Therefore moulding moisture content of OMC+4% for lime treated mixes except the mix BC soil+15%RHA+6%lime, for which OMC+6% are the normal moisture content at which compaction can be done to ensure maximum strength. Table 4 shows the percentage increase in the UCS values of lime treated BC soil and BC soil-RHA mixtures due to MMC compared with the values at OMC condition. It can be seen the UCS values are again maximum with the mix BCsoil+10%RHA+6% lime, compacted at MMC=OMC+4%. Therefore using 10 % RHA and 6 % lime by weight of BC soil and compacted with moisture content of OMC+4% is more beneficial in BC soil region. Chandra et al., (2002) have carried out test on clayey soil of low compressibility using RHA and lime sludge compacted at MDD and OMC. It is observed that UCS of clayey soil exhibited maximum with the combination of 10% RHA and 16% lime sludge.

The strength values of RHA-lime stabilised BC soil compacted with MMC of OMC-2% and OMC-4% decreased below the strength values compacted at OMC condition. This indicates that sufficient water is not available for pozzolanic reaction to form cementitious compounds and liberation of heat during hydration weakens stabilised soil structures. Figures 9, 10, and 11 shows the strength characteristics behaviour of samples compacted at MDD with different MMC for different curing periods. It is observed that, UCS curves of lime treated soil and soil-RHA mixtures continue to increase in their strength even after 28 days of curing period except the samples compacted with OMC-4%. This indicates that the pozzolanic reaction is time dependent and hence cementitious compounds formed accordingly and influences on strength of stabilised soil.

Table 4 Effect of Moisture Content on UCS and CBR of Soil-RHA-Lime Mixes

Curing Period (Days)	***UCS (kPa) At***		***% Increase in UCS of Vis- a -Vis (1) and (2)***	***CBR (%)At***		***% Increase in CBR Vis- a-Vis (3) and (4)***
	*MMC (1)	OMC (2)		MMC (3)	OMC (4)	
Sample: BC soil+6%L						
0	490.64	504.20	-2.69	21.04	24.19	-13.02
4	1084.62	959.57	13.03	44.82	40.05	11.91
7	1726.76	1554.52	11.08	51.57	45.48	13.39
14	2217.94	1808.64	22.67	59.13	53.84	9.82
28	2564.17	2144.34	19.57	62.08	57.36	8.22
Sample: BC soil+5%RHA+6%L						
0	453.10	528.67	-14.29	22.85	28.48	-19.76
4	1388.83	988.29	40.53	51.17	45.14	13.36
7	2182.83	1665.52	30.99	63.38	52.86	19.9
14	2726.25	1989.83	37.04	69.14	60.94	13.45
28	3034.84	2298.67	32.02	72.36	65.45	10.55
Sample: BC soil+10%RHA+6%L						
0	415.4	570.6	-27.19	29.05	33.03	-12.05
4	1718.64	1272.34	35.07	63.46	48.42	31.06
7	2422.51	1798.18	34.72	78.67	61.37	28.18
14	3079.63	2127.26	44.77	89.77	72.14	24.43
28	3583.48	2685.44	33.44	94.33	77.54	21.69
Sample: BC soil+15%RHA+6%L						
0	320.75	426.34	-24.76	22.86	24.08	-5.06
4	1602.73	1168.19	37.19	46.98	38.15	23.14
7	2002.15	1413.35	41.65	53.63	42.57	26.09
14	2269.78	1596.71	42.15	60.65	46.84	29.48
28	2626.34	1938.38	35.49	63.78	50.27	26.87

* MMC= Moulding Moisture Content = OMC+4% except for mix BC Soil+15%RHA+6%L, for which MMC= OMC+6%.

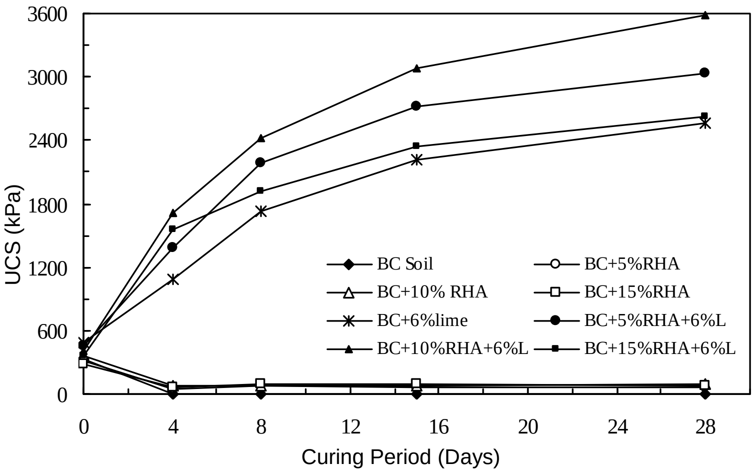

Fig. 9 Effect of Curing on UCS of BC Soil-RHA-Lime Mixes, Compacted @ MDD with MMC=OMC+4%

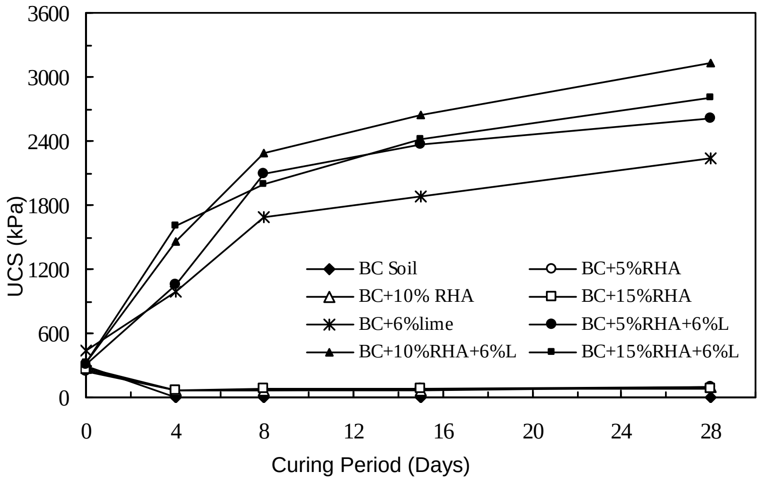

Fig. 10 Effect of Curing on UCS of BC Soil-RHA-Lime Mixes, Compacted @ MDD with MMC=OMC+6%

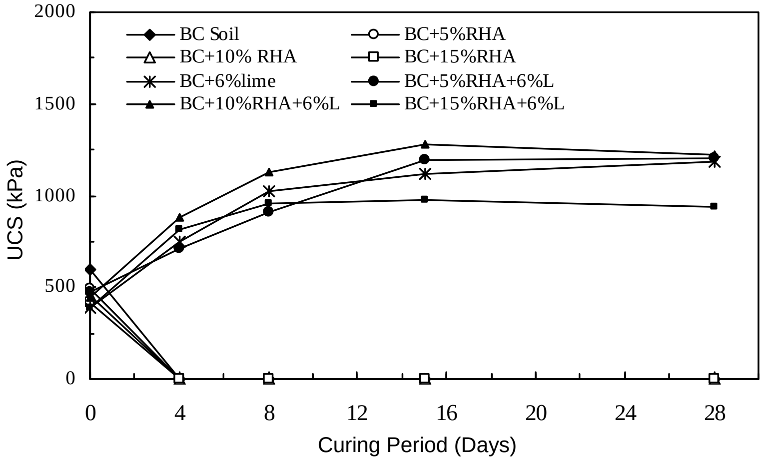

Fig. 11 Effect of Curing on UCS of BC Soil-RHA-Lime Mixes, Compacted @ MDD with MMC=OMC-4%

CBR Tests Results

Effect of RHA and Lime Addition on CBR of Soil

Figure 12 shows the influence of curing period on CBR of BC soil treated with RHA, lime and RHA-lime mixtures, compacted at MDD with OMC.

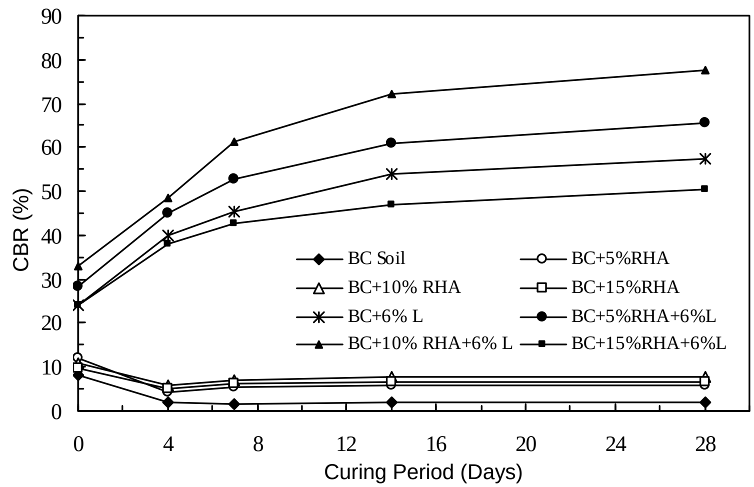

Fig. 12 Effect of Curing on CBR of BC Soil-RHA-Lime Mixes, Compacted @ MDD with OMC

It is observed that soaked CBR of lime treated combination of BC soil and BC soil-RHA mixtures increased with curing periods and Maximum CBR is found with the mix BC soil+10%RHA+6%lime at 28 days of curing period. Soaked CBR of BC soil at 15% RHA content with 6%lime decreased, indicates that the formation of cementitious compounds are not depends on the amount of silica but also depends on the pH of lime which is available for pozzolanic reaction (Ramesh et al., 1999).

Effect of Moulding Moisture Content on CBR of Soil-RHA-Lime Mixes

Figure 13 shows the results of CBR of samples tested at increased moisture content (MMC) beyond OMC.

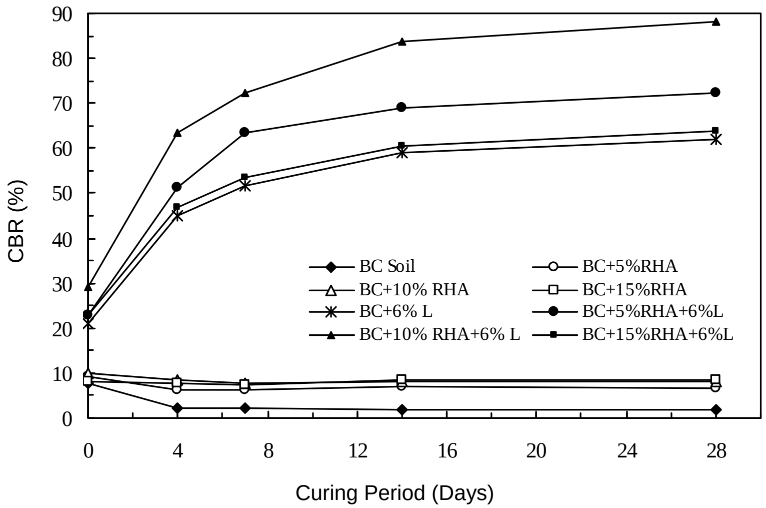

Fig. 13 Effect of Curing on CBR of BC Soil-RHA-Lime Mixes, Compacted @ MDD with Moulding Moisture Content (MMC)

It is observed that, unsoaked CBR values of all mixtures of samples compacted at MMC exhibit slightly less value than at OMC values. In soaked condition, CBR of lime treated BC soil and BC soil-RHA mixtures showed higher values than at OMC values. This indicates that the excess water at increase moisture content will influences in the formation of gel pores to produce more cementitious products. Therefore, this brings greater resistance against plunger penetration, which leads to exhibit peak CBR values of mixtures. It is again observed that the maximum CBR found with the mix BC soil+10%RHA+6%lime, compacted at moulding moisture content of OMC+4%. Therefore use of 10%RHA with 6%lime with increased moisture content by 4% beyond OMC in BC soil is more beneficial to stabilize. Percentage increased in the CBR value of BC soil mixed with lime and RHA-lime combinations due to increase in the moulding moisture content beyond OMC is presented in Table 4.

Conclusions

Based on the results obtained in this study the following conclusions are drawn.

1. High plastic nature of BC soil reduced to low plastic due to addition of RHA and lime combination. The plasticity index of soil decreased due to decrease in the value of liquid limit and increase in the value of plastic limit of soil. At 6% lime content plasticity of BC soil–RHA mixes reached to a minimum value and beyond 6% lime content further decrease in the plasticity index is insignificant.

2. Maximum dry density of soil decreases with the increase in RHA content associated with increased OMC. The changes further increased with the addition of 6% lime to BC soil-RHA mixtures.

3. UCS value of RHA-lime stabilised BC soil increased with curing period and is maximum for the mix BC soil+10%RHA+6%lime at 28 days of curing.

4. The gain in strength due to increase in moisture content beyond OMC is maximum at OMC+4% for mixes BCsoil+6%lime, BC soil+5%RHA+6%lime and BC soil+10%RHA+6%lime and for mix BC soil+15%RHA+6%lime the maximum strength found at OMC+6%.

5. Unsoaked CBR value of mixes BC soil-RHA with no lime content compacted at MDD with OMC higher than the soaked values. An increase in moulding moisture content beyond OMC brings down slightly the unsoaked CBR values of these mixtures.

6. Soaked CBR of BC soil treated with lime and RHA-lime mixes increased with the curing period and maximum CBR found with the mix BC soil+10%RHA+6%lime at 28 days of curing period. An increase in moisture content beyond OMC on wet side of optimum increases the soaked CBR of lime and RHA-lime treated BC soil and values are above the OMC values at all levels of curing periods.

Therefore, when preparation of sub-base/sub-grade of pavement in Rice Husk Ash-lime stabilised BC soil, is best to be compacted the mixture with increased moisture content beyond OMC on wet side of optimum. To achieve best suited results one has to determine the peak value of moisture content (critical moisture content) at which strength is maximum for the particular soil and stabilizer used.

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