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Study of Variation in Moulding Water Content on the Strength Properties of Red Earth Soil Treated with Additives

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Abstract

Non Expansive (NE) soils are known as Red Earth (RE) soils in Karnataka, India and are non-expansive in nature. Kaolinite clay mineral is the component responsible for NE behaviour of soil. Beyond Optimum Moisture Content (OMC), soil whether are expansive or non-expansive, lose their stiffness and strength. To assess the role of Moisture Content (M/C) on RE soil and with additives such as Bagasse Ash (B.A.), lime (lm) and calcium salts (calcium sulphate and calcium chloride), an investigation has been carried out. Various laboratory tests such as Atterberg's, limit, compaction and unconfined compressive strength tests have been carried out on RE soil which is treated with additives. B.A., lm and calcium salts changed the Atterberg's limit of RE soil. At Dry of Optimum (DOO) to Wet of Optimum (WOO) condition, compaction test was conducted. Compaction characteristics varied with the addition of additives with varying moulding water content. However, B.A. addition gives only mechanical effect and strength improvement is marginal. Along with B.A., lm and Calcium Chloride (CC) are added to soil which gave promising results due to formation of amorphous gel like substance. Calcium Sulphate (CS) addition is not recommended for soil due to decrease in strength with curing. The strength achieved for the soil compacted at DOO is more pronounced as compared to soil compacted at WOO.

Keywords: *Bagasse Ash, Calcium Salts, Lime, Red Earth Soil*

1.0 Introduction

Bengaluru in Karnataka is covered with Red Earth soil (RE) which is Non Expansive (NE) in nature since the mineral content is kaolinite. Beyond Optimum Moisture Content (OMC), the soil whether are expansive or Non-Expansive (NE), lose their stiffness and strength. Such loss in strength is due to inter-particle repulsive forces, results in the most orderly arrangement of particles at a given compactive effort and dry unit weight[1]. However, the maximum strength of soil is achieved at Dry of Optimum conditions (DOO), due to the flocculated/ aggregated structure in material[2]. Water Content (w/c) plays important role especially for hydraulic barrier application, where the soil particles are deflocculated with increased Water Content (w/c). The soil matrix shows decreased void spaces when compacted at higher water w/c with low hydraulic conductivity[3]. The strength of stabilized soils also varies with variation in moulding water content[4]. If the locally available soil is cohesive non swelling soil like RE soil, then such soil and lm mixture can be used as cushion material, which can bring the swell shrink behaviour of expansive soil under permissible bounds[5]. Various stabilizers have been used to stabilize soil for geotechnical applications and one amongst them is Bagasse Ash (B.A.). The incineration of bagasse in sugar industries produce bagasse ash with higher percentage of silica and low percentage of calcium oxide, which can be

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categorised as pozzolanic material[6,7]. Waste management problem arises for sugar industries with the production of B.A. in large quantity. Therefore, this investigation aims at effective utilization of B.A. for stabilization of RE soil. B.A. alone cannot be used to enhance the strength of RE soil since the lm content is low. Along with B.A. lm is also added which can bring about the improved strength properties. Addition of lm to soil-water system cause increase in soil pH due to which alumina and silica are released, takes part in pozzolanic reaction with calcium from lm to form cementitious Calcium Silicate Hydrate (C.S.H) and Calcium Aluminate Hydrate (C.A.S.H) gel like compounds. The pozzolanic reaction compounds increased the strength properties of lm stabilized soil[8]. Many researchers have reported the beneficial use and detrimental effects of calcium salts. Cat-ion exchange is not the only the reason for modification of soil with Calcium Chloride (CC) but also it can enter the spaces of clay which can bringing about significant change in clay behaviour. Use of Calcium Sulphate (CS) has deleterious effects on stabilized soil. Loss in strength of soil is observed if the soils contain sulphates[9]. Therefore, the study mainly aims to know how RE soil behaves with the variation of moulding w/c with additives such as B.A., lm and calcium salts.

2.0 Materials and Methods

The various materials used to prepare the soil samples and the methods adopted for testing have been discussed in detail and are presented.

2.1 Materials Used for the Study

RE soil, B.A., lm and calcium salts have been used in the present study, their properties and chemical composition are discussed and are presented.

2.1.1 Red Earth (RE) Soil

RE soil for the present study is obtained from Bangalore University, Bengaluru, Karnataka state, India. It is red in colour due to the presence of Iron oxide. The soil which is collected has been sieved through 425 micro meter Bureau of Indian Standards (BIS) sieve. Soil is classified as medium plastic clays (CI) as per BIS Soil Classification system. Grain Size Distribution (GSD) as well as its physical properties are shown in Figure 1 and Table 1 respectively.

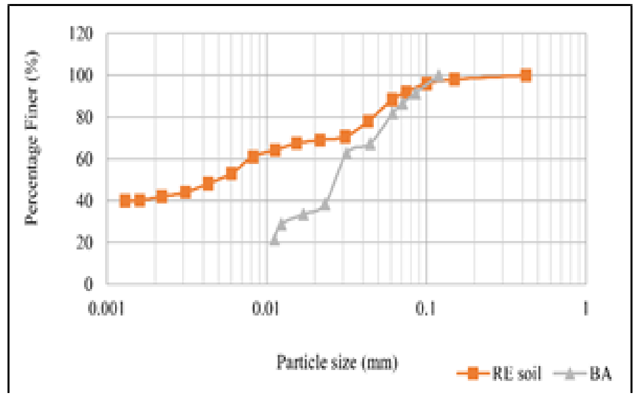

Figure 1. Grain size distribution curve for RE soil and B.A.

Table 1. Physical property of RE soil and B.A.

Property	RE soil	B.A.
Specific gravity	2.68	1.71
Sand (4.75–0.075 mm) (%)	8	12
Silt (0.075–0.002 mm) (%)	52	66.4
Clay (<0.002 mm) (%)	40	--
Liquid limit (%)	39	61
Plastic limit (%)	22	Non plastic
Plasticity index (%)	17	--
Shrinkage limit (%)	15	--
Max. dry unit weight (kN/m^3)	18	10.34

2.1.2 Bagasse Ash (B.A.)

Mandya district in Karnataka is known for sugar industries. Bagasse Ash (B.A.) is collected from sugar industry which is the product after burning bagasse. It is burnt again in an oil fired furnace in Peenya Industrial area, Karnataka, India to remove organic content its GSD as well as chemical composition is shown in Figure 1 and Table 2 respectively.

2.1.3 Lime (LM), Calcium Sulphate (CS) and Calcium Chloride (CC)

Lab grade pure hydrated lm, CS and CC have been used.

2.2 Methodology

Atterberg's limit, Grain size analysis, compaction tests and Unconfined Compressive (UCC) strength tests have been carried out for samples. Specific gravity test for soil and B.A. is conducted as per IS 2720-3(Sec1): 1980

2.2.1 Grain Size Distribution (GSD)

Hydrometer analysis has been carried out for RE and B.A. as per IS 2720-4: 1985 to obtain grain size distribution shown in Figure 1.

2.2.2 Atterberg's Limit Test

Atterberg's limit test have been determined for both immediate as well as for 7 days of curing as per IS 2720-5:1985.

2.2.3 Compaction Test

A small compaction test apparatus is used to find dry unit weight and Moisture Content (M/C) of RE soil alone and for soils treated with B.A. and lm in the presence of calcium salts for various moulding w/c. The design of this equipment is documented in[10]. The results of obtained are shown in Table 3.

2.2.4 Unconfined Compressive Strength (UCC) Test

The UCC tests were carried out for the samples and are prepared by thoroughly mixing soil, B.A., lm, calcium salts and water. Soil, water and additive mixture were statically compacted for the predetermined unit weight as shown in Table 3. The cylindrical mould has been used for preparing the soil sample and its height is h = 0.076 m. Radius of the mould is 0.019 m. Desiccators are used to keep the soil samples which are air tight. Polythene bags which were having zip lock have been used to keep the soil samples so as to prevent them affected from atmospheric temperature and air and were cured up to a required time period. Soil samples were checked to know the effect of weather by constantly checking the weight. The procedure given in n IS 2720-10:1991 is followed for preparing the soil samples and procedure which mention a constant strain rate of 1.25 mm/min has been applied while conducting the experiments. For the samples prepared at each selected unit weight on the DOO, optimum and WOO on the compaction curves obtained have been tested and reported.

3.0 Results and Discussion

Figure 2, gives the details of various combinations of soil and additives, the left side of Optimum Moisture Content (OMC) is DOO and the right side of OMC is WOO. Dry unit weight and water content at DOO, optimum and WOO conditions are read from the compaction curves. Maximum dry unit weight of 95% were selected both on left and right side of optimum. The corresponding values of w/c and dry unit weight values are tabulated in Table 3.

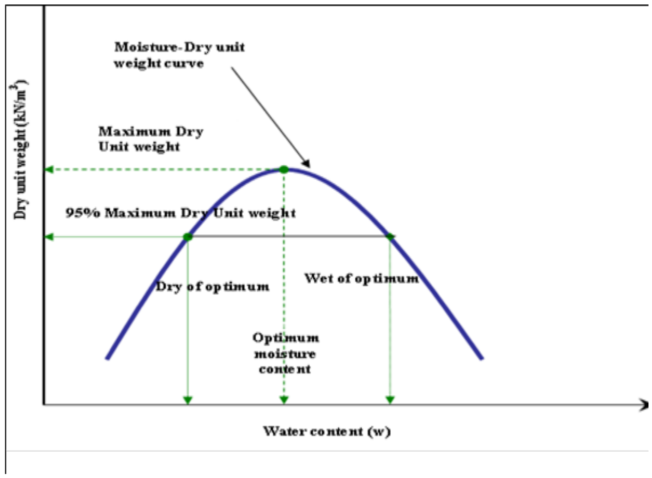

Figure 2. Dry unit weight and w/c relationship at a particular compactive effort.

Table 2. Chemical composition of B.A.

Material	Silica (SiO_2)	Alumina (Al_2O_3)	Ferric oxide (Fe_2O_3)	Calcium oxide (CaO)	Magnesium oxide (MgO)	Sodium oxide (Na_2O)	Potassium oxide (K_2O)	Loss on ignition
B.A.	65.92	11.96	2.86	5.6	4.03	1.79	3.19	16.18

Table 3. Variation of dry unit weight and w/c for RE soil and B.A. combination treated with lm in the presence of calcium Salts

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 (%)
RE Soil alone	15.58	16	16.4	18	15.58	20
RE Soil + 10% B.A.	14.5	17	15.4	20	14.5	22
RE Soil + 10% B.A. + 2% lm	13.8	18	14.5	22	13.8	27
RE Soil + 10% B.A. + 2% lm + 1% CS	14	20	14.7	26	14	28
RE Soil + 10% B.A. + 2% Lime + 1% CC	14.1	21	14.8	27	14.1	30

Table 4. Index properties of RE soil treated with B.A., lm and calcium salts

Combination	LL (%)		PL (%)		SL (%)		PI	
Curing days	0	7	0	7	0	7	0	7
RE soil alone	39	-	22	-	15	-	17	-
B.A. alone	61	-	Non Plastic					
RE soil+10% B.A.	44	46	28	30	20	22	16	16
RE soil+10% B.A. +2% lm	49	51	35	37	24	25	14	14
RE Soil+10% B.A. +2% lm+1% CS	47	49	33	35	25	26	14	14
RE soil+10% B.A.+2% lm +1% CS	46	48	33	34	25	26	13	14

3.1 Atterberg's Limit of RE Soil Treated with B.A., lm and Calcium Salts

Atterberg's limit/consistency limits such as liquid limit, plastic limit and shrinkage limit varies when clay content varies and also the type of clay mineral contribute to these variations. Exchange of Ions, reactivity by pozzolans and diffuse double layer thickness are also the factors which govern the alteration in Index properties when fly-ash, rice husk ash, lm etc. are incorporated into clayey soil[11]. Optimum dosages of B.A. and lm to be added to RE soil have been shown in Figure 4 and Figure 5 respectively for the samples tested immediately and for the samples cured for seven days. A negligible variation in Index properties have been observed with the addition of additives to both the soils and has been shown in Table 4 and discussed in detail[12].

3.2 Optimization of B.A. and lm for RE Soil

To find optimum dosage B.A. for RE soil, B.A. is added in an increment of 5% up-to 30% (5% to 30%). Marginal strength enhancement is seen as shown in Figure 3. This may be due to during samples preparation process there is every possibility of onset of pozzolanic reaction. Pozzolanic reaction is between free lime content of B.A. and silica and alumina present in B.A. and clay. Strength increased up to 10% B.A. is added. Beyond 10% B.A. addition, strength decreased which may be attributed to the clay matrix being disturbed with an increase in B.A. content and making the soil less clayey. With curing, UCC strength increased up to 10% B.A. addition which may be attributed to the compounds formed during pozzolanic reaction overrides the silty particles of B.A. Therefore 10% B.A is considered as optimum dose for RE soil.

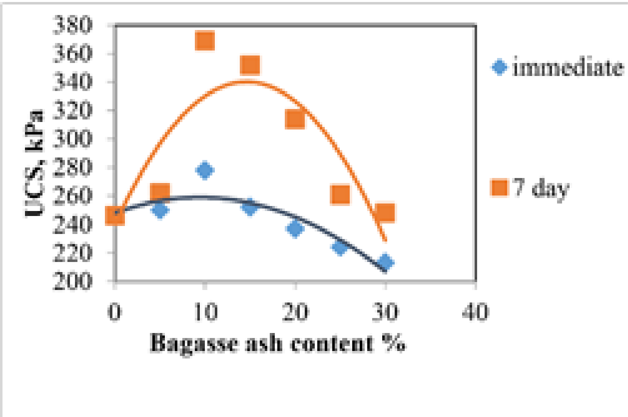

Figure 3. Optimization of B.A. for RE soil.

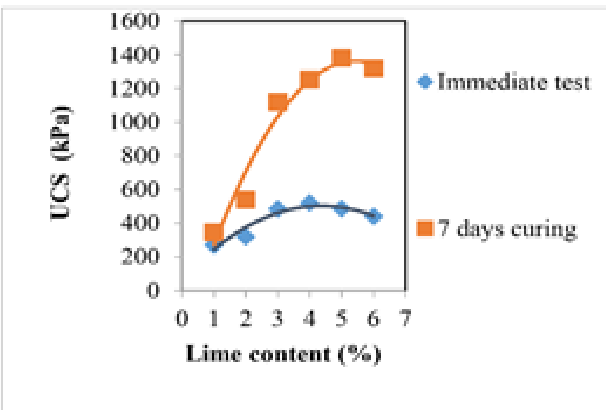

Figure 4. Optimization of lm for RE soil + B.A. mixture.

Calcium oxide present in lm is the main compound responsible for strength gain in most of the lm and soil combination.

However, in the presence of water, the pozzolanic reactions are more pronounced with the pozzolanic compounds formation and these reactions are responsible for strength gain. UCC strength of soil - B.A. mix enhanced up to 2% of lm addition beyond which strength decreased as shown in Figure 4 which may be due to the formation of C.S.H compound. Same trend is also observed with curing period of seven days. When lm is added more than 2%, strength decreased. Hence 2% lm is the optimum dosage in the present investigation.

3.3 Variation in Moulding w/c and its Effect on UCC Strength of RE Soil B.A. Mix

B.A. which is an industrial waste when added to RE soil,

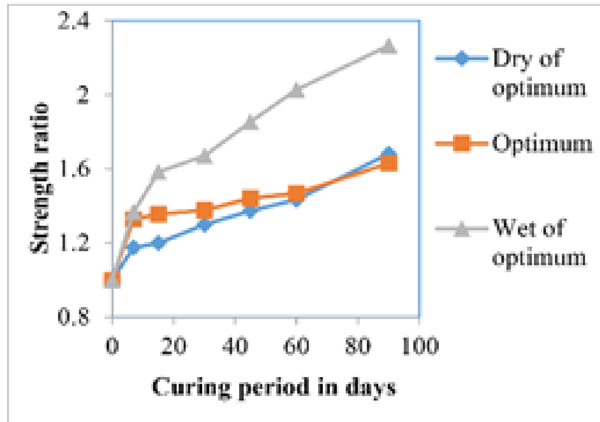

Figure 5. SR of RE soil and B.A. mix at various moulding w/c with curing.

marginal strength gain has been observed for all moulding w/c (DOO, Optimum and WOO) with curing period due to flocculation of particles. Strength at DOO is more significant shown in Tables 4-6 when comparison is made with optimum and WOO. This is mainly because of the change in structure of the soil with change in moulding w/c and bond formation. However, the bonds break at higher w/c and as a result, the strength developed is not pronounced at WOO. To evaluate strength increase due to the onset of pozzolanic reaction, strength variation is considered as the Strength Ratio (SR)[13]. The ratio of the strength of the mixture with curing to that of strength without curing, compacted at the same w/c and respective dry densities is defined as SR. When curing period varied then SR value also changed and is depicted in Figure 5, at DOO to WOO conditions. It was found that the strength ratio is more pronounced at WOO with more availability of water for the reaction[14].

3.4 Variation in Moulding w/c and its Effect on UCC Strength of RE soil, B.A. and lm Mix

As per chemical analysis, shown in Table 2, the CaO percentage is less which is not sufficient to complete pozzolanic reaction and develop C.S.H and C.A.S.H amalgams. Therefore lm is added which is rich in calcium oxide. UCC strength of the composite is the maximum at ninety days of curing shown in Tables 5-7 for all the samples compacted at various moulding water contents, can be emphasized that crystallization of pozzolanic compounds. As curing time increases, the

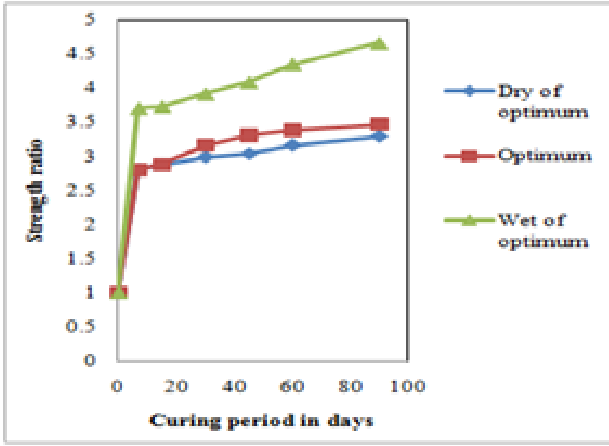

Figure 6. SR of RE soil and B.A. mix treated with lm at various moulding w/c with curing.

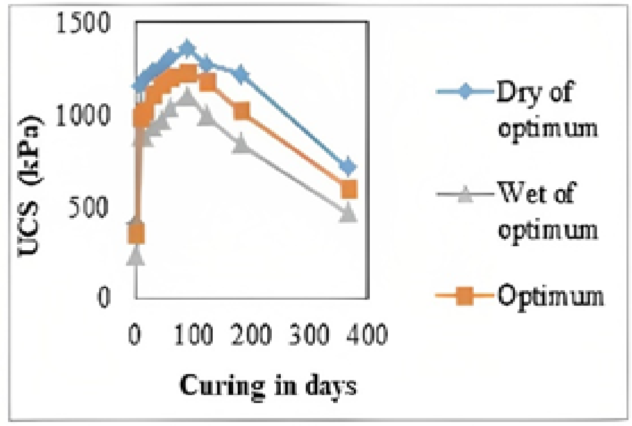

Figure 7. SR of RE soil, B.A., lm treated with CS at various moulding w/c with curing.

strength of the treated soil also enhances[15]. At DOO, the cementitious products fused the clay particles and edge to face flocculated structure is seen on the DOO which exhibited strong bond[4]. As seen from Figure 6, the SR is more pronounced on WOO which indicates that the rate of strength increase is enhanced since more water is available for pozzolanic reaction.

3.5 Variation in Moulding w/c and its Effect on UCC Strength of RE Soil, B.A., lm and Calcium Salts Mix

To know how sulphate reacts with soil + B.A. + lm mixture, CS is added though literature show that CS addition to lm-soil mix gives detrimental results. Higher dosage of sulphate causes increased water absorption and swelling in soil-kaolinite combination which is detrimental to lime treated soil[16,17]. Hence one percent CS is selected as the optimum dosage in the present investigation. However, to study the sulphate effect, which can be observed at longer curing time/period, the composite treated with sulphate have been cured up to 365 days.

The strength of sulphate treated soil increased on immediate testing at DOO, optimum and WOO shown in Tables 5-7. This improved strength is due to the formation of ettringites, needle like structures which are formed due to the reaction between negative ions of sulphates, calcium from B.A. and lm with alumina. C.A.H and C.A.S.H compounds formation is suppressed when ettringites are formed which may be due to depletion of alumina. The voids or the pore spaces of clay are filled with ettringites and thus the strength improvement is observed on samples tested immediately[18]. At DOO, the strength improved by 2.8 to 3.29 folds at 7-90 days of curing. At optimum conditions, the strength improved by 2.8 to 3.47 folds at 7-90 days of curing. At WOO, the strength improved by 3.71-4.66 folds at 7-90 days curing as shown in Figure 5. Formation of increased cementitious compounds is the main reason for the enhancement of UCC strength with increased supply of Ca^{+2} ions which accelerates the soil-lm reaction with the addition of gypsum. With 120 days of curing, the strength decreased and further decrease in strength is observed at 180 days of curing for all the moulding w/c. The decrease in strength is due to the enhanced growth of ettringites in the clay matrix which are expansive in nature and cementing ability of the soil is reduced.

At 365 days of curing period, the strength reduced drastically due to the disturbance of clay medium with the further growth of sizeable ettringites. However, for this combination also the strength achieved at DOO conditions is highly substantial as compared to optimum and WOO. This may be attributed to ample amount of water which is sufficient for growth small ettringites. SR improved up to ninety days of curing which is shown in Figure 7 for all the moulding w/c, however SR declined for 120, 180 and 365 days of curing period. For this combination too SR is more pronounced at WOO.

Calcium Chloride (CC) is deliquescent in nature. It absorbs atmospheric moisture and forms its own solution, when dissolved in water.Ca^{+2} and Cl^{-2} ions are dissociated into the solution. An excess of Ca^{+2} ions are supplied to the stabilized clay system to accelerate the pozzolanic

Table 5. Variation in moulding w/c and its effect on UCC strength of RE soil, B.A., lm and calcium salts mix at DOO

Combinations	UCS at dry of optimum (kPa) Curing in days									
	0	7	15	30	45	60	90	120	180	365
R. E soil alone	329	-	-	-	-	-	-	-	-	-
R. E soil + 10% B.A.	332	390	398	431	456	476	558	-	-	-
R. E Soil + 10% B.A. + 2% lime	342	887	963	1013	1277	1352	1493	-	-	-
R. E Soil + 10% B.A. + 2% lime + 1% calcium sulphate	412	1155	1184	1229	1249	1301	1354	1273	1219	710
R. E Soil + 10% B.A. + 2% lime + 1% calcium chloride	375	1135	1164	1206	1319	1423	1565	-	-	-

Table 6. Variation in moulding w/c and its effect on UCC strength of RE soil, B.A., lm and calcium salts mix at optimum

Combinations	UCS at optimum (kPa) Curing in days									
	0	7	15	30	45	60	90	120	180	365
R E soil alone	246	-	-	-	-	-	-	-	-	-
R E soil + 10% B.A.	278	369	377	383	401	408	453	-	-	-
RE soil + 10% B.A. + 2% lm	309	770	841	902	1176	1206	1272	-	-	-
RE soil + 10% B.A. + 2% lm + 1% CS	354	990	1020	1118	1170	1198	1227	1179	1021	601
RE soil + 10% B.A.+ 2% lm + 1% CC	323	941	970	1004	1216	1314	1327	-	-	-

Table 7. Variation in strength of RE soil and B.A. mixture treated with lm in the presence of Calcium salts at wet of optimum condition with curing at WOO

Combinations	UCS at WOO (kPa) Curing in days									
	0	7	15	30	45	60	90	120	180	365
R E soil alone	176	-	-	-	-	-	-	-	-	-
R E soil + 10% B.A.	185	253	293	309	343	375	419	-	-	-
RE soil + 10% B.A. + 2% lm	194	642	781	856	985	1095	1154	-	-	-
RE soil + 10% B.A. + 2% lm + 1% CS	237	878	883	928	968	1031	1104	995	842	470
RE soil + 10% B.A.+ 2% lm + 1% CC	218	725	830	868	1087	1125	1236	-	-	-

reaction. The pozzolanic reaction acceleration results in cementitious compounds formation due to which the strength of the soil is enhanced. Various investigations have focussed towards use of 1% CC to stabilize the soil[19].

Soil samples when they are tested immediately and up to ninety days of curing, UCC strength of soil+B.A.+lm mix enhanced from DOO to WOO. It is observed from Tables 5-7 that the strength increased up to 90 days of curing

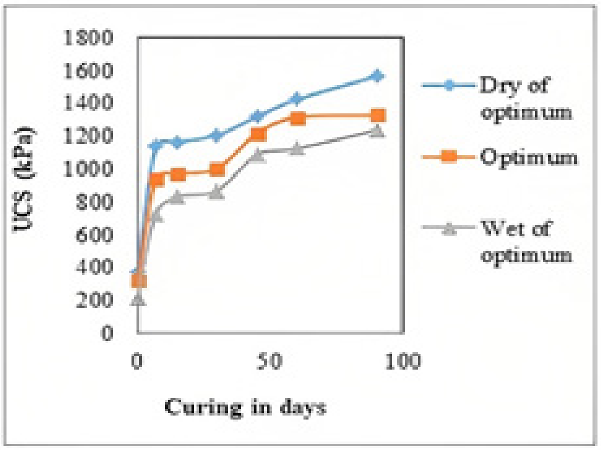

Figure 8. SR of RE soil, B.A., lm treated with CC at various moulding w/c with curing.

period. Because of the ready dissolvability of calcium chloride in water, which supplies more calcium ions to the soil system. Thus pH of the system increased which favours the enhanced pozzolanic reaction. The pozzolanic compounds formed are held together to form a cluster and due to which the strength improved. Bond strength increased with curing, which eventually leads to more strength[20].

SR increased for the samples tested immediately without curing and further enhancement of strength observed for the cured samples shown in in Figure 8. However, the samples compacted at WOO showed greater gain in strength as compared to other w/c when water available is sufficient for the formation of cementitious gel.

4.0 Conclusion

Results have been analysed and conclusions are presented as below.

Variation of Atterberg's limit were observed due to the agglomeration of particles with additives and the gradation of soil changed. An optimum dosage of B.A. (10%) and lm (2%) is found out for RE soil. The strength of RE soil and B.A. mixture, increased with curing period at DOO to WOO conditions which is due to the flocculation of particles. Lime is added since soil-B.A. mixture did not show significant strength improvement. With lm treatment, the peak stress increased for the samples moulding w/c got from compaction for the cured samples for all the moulding w/c due to the development of C.S.H and C.A.S.H gel to form closely packed matrix which sealed the voids in the medium. Sulphate addition to soil B.A.-lm composite decreased the strength beyond longer curing days due to the further growth of ettringites which are expansive in nature. Calcium chloride addition to RE soil –B.A.-lm mixture, the peak stress of the samples compacted at the moulding w/c enhanced with curing which is attributed to the pozzolanic materials formed with more availability of calcium ions to the soil mass due to the hygroscopic nature and ready dissolvability of calcium chloride. With the more supply of calcium ions, a gelly like substance i.e., C.S.H and C.A.S.H substances are formed. At DOO UCC strength is more pronounced as compared to optimum and WOO because of aggregation (more bond strength) of soil particles. At WOO, the strength achieved is not pronounced since the bonds breaks at higher water contents. The strength ratio is more significant on WOO condition for all the combinations due to enhancement in pozzolanic reaction with more availability of water.

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