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Improvement of Poor Subgrade Soil using Calcium Carbide Residue

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Abstract. Improving subgrade properties using traditional additives such as lime and Portland cement adds supplementary costs. Therefore, using the product in this domain involves technical, economic, and environmental advantages. The current study explores the construction of a weak layer of subgrade and strengthening it by using the industrial by-product of Calcium Carbide Residue (CCR), a waste by-product of an acetylene gas production process. The stabilized soil's compaction, strength, and California Bearing Ratio were observed under different curing times. The specimens were compacted at optimum water content. CCR is rich in $Ca(OH)_2$ because clayey soils contain a high amount of silica and alumina, natural pozzolanic materials. The input of CCR reduces the plasticity index of the clay, increases the optimum water content, and decreases the maximum dry unit weight of the stabilized clay. Further analysis shows that increasing the proportion of CCR increases the peak strength (UCS) of the treated soil up to 61 % for a maximum of 28 days of curing. The combination of the CCR can be successfully used in stabilization works and to utilize the waste by active minimization giving solutions to disposal problems.
Keywords: Expansive Soil; Calcium Carbide Residue, CBR, UCS, Compaction

1. Introduction:

Construction of roadways over expansive soil and soft clay is the most common problem in highway construction in most parts of India. For developing infrastructure facilities, highway engineers face difficulty finding suitable subgrade soil. Expansive soil deposits formed from basaltic rocks are spread over a large area in tropical countries. Due to high percentages of montmorillonite minerals, expansive soil is a problematic material for constructing foundations and pavement. Pavement construction over the expansive soil subgrade is a serious concern to civil engineers due to volumetric changes and reduction in strength and stiffness due to the variation in moisture content, leading to distress in the pavements. The remove and replacement approach has been traditionally used to overcome the problem of soft subgrade stabilization; however, such an approach proved to be uneconomical and time-consuming. High replacement costs have caused highway agencies to evaluate alternative highway construction methods on soft subgrades. Researchers included recycled crushed glass, broken bricks, recycled construction materials aggregate, and traditional stabilizer lime and cement frequently used to improve subgrade. [1,2]. Improving subgrade properties using waste materials for pavement applications is of great international concern. Chemical stabilization is widely used for soil improvement techniques.

Recently, researchers have shifted towards using calcium-based industrial by-products for stabilization. As calcium-based products carriages, cementations material properties and gives alternate solution for cement. In recent years, calcium carbide residue (CCR) has been identified as an alternative and sustainable stabilization additive [2,3]. CCR is a by-product generated at the time of production of the acetylene gas. CCR contains mainly calcium hydroxide Ca(OH)2. The high Ca(OH)2 and CaO contents of CCR indicates that it can react with pozzolanic material such as CSA and produce a cementation material. For example, the following reaction occurs when calcium carbide reacts with water [4].

The following equation best describes the production of CCR:

$$CaC_2+2H_2O \rightarrow C_2H_2 + Ca(OH)_2 \quad \textbf{(1)}$$

From Eq. (1), it can be seen that when calcium carbide reacts with water, the result so obtained is in the form of acetylene gas (C2H2) and CCR in the form of Ca(OH)2.[4] CCR is predominantly in a slurry form and is characterized by high alkalinity and water content, which, unfortunately, becomes a source of pollution to the surface and ground- water [3]. The use of CCR is a cost-effective and environmentally safe industrial waste by-product of acetylene gas. In India, CCR has zero recovery value. It is a practice to dump it in open lands or landfills. This has adverse impacts on the landfill volume and reduces the biodegradation process of many other wastes due to its high alkali content. The strength, durability, and microstructure of CCR-stabilized soils have been studied to evaluate their viability as a bound pavement material [5,6]. Studies also reported that the input of CCR significantly reduced the specific gravity and plasticity of virgin soils. At the same time, it is seen that there is a successive increase in the strength of the soil. It is necessary to develop means to reuse this industrial waste to support the environ- ment.

This paper investigates the poor highway subgrade after the addition of CCR. To check the effect of CCR on Soil Specific Gravity, Consistency limit and compaction characteristics were determined with varying percentages of CCR (2, 4, and 7). Unconfined compressive strength and California Bearing Ratio (CBR) test were practical indicators of strength development. Test samples were prepared and examined under different curing times (7, 14, and 28 days). Relations between curing time and strength were developed. This research will assist engineering decisions on the mixed proportion of soil, water, and CCR. In addition, it explored the construction of weak layers using CCR.

2. Materials and Methods

2.1 Soil Sample:

The sample was collected from Mithila Project at Aayavarta, Mahale Estate, Maharana Pratap Chowk, Nashik. The location is part of Central India, the area covered by the expansive soil commonly known as black cotton soils. Undisturbed soil samples were collected from three test pits at a depth of 0.5 to 2.5m from the site. Test pits were excavated at three locations, as shown in figure.1.

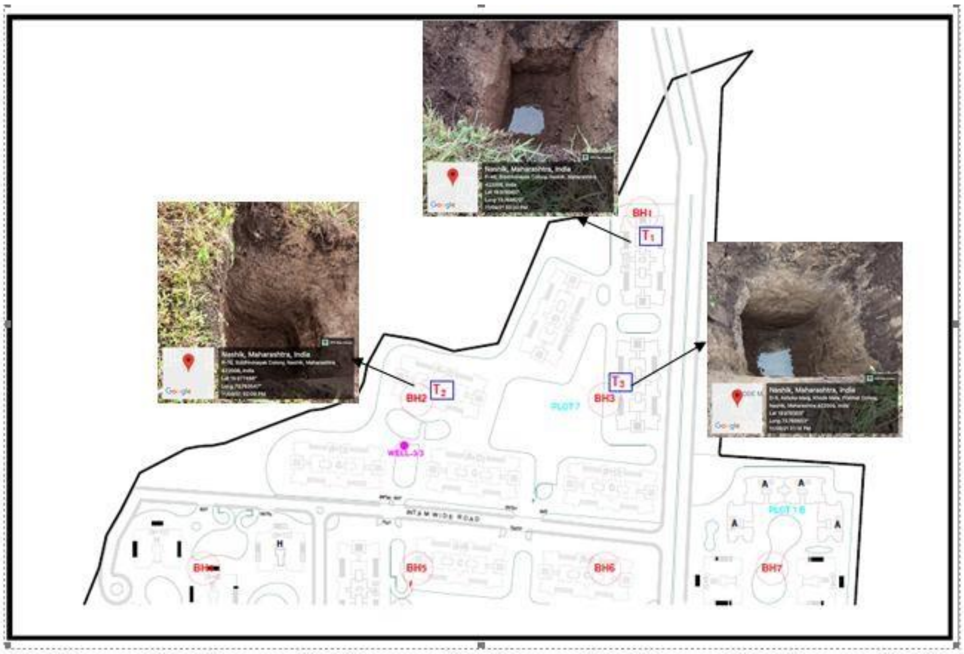


Fig.1. Location Map

The natural water content of the soil was 32%. Figure 2 shows the composition of various particles in expansive soil as 5% sand, 34% silt 61.7 % clay. It indicates that the proportion of fine particles exceeds 90%. According to the Unified Soil Classification System (USCS), expansive soil is classified as clay with high plasticity (CH). The specific gravity of the soil was 2.63. The liquid and plastic limits were 63% and 36%, respectively. The presence of SiO_2, Al_2O_3, and Fe_2O_3 was high enough for the pozzolanic reaction.[8] The soil was crushed into particles after being air-dried and sieved with a sieve of 4.25um. Specific gravity, Consistency limit, compaction characteristic, and Differential free swelling index were tested and listed in Table 1.

Table 1. Physical properties of expansive soil.

Specific Gravity	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index	Free swelling Ratio(%)	Swelling Pressure (kPa)	Maximum dry density (KN/m$^{3)}$	Optimum moisture Content(%)
2.63	65	22	43	75	147.2	14.35	25

The particle size distribution of expansive soil is shown in Fig.2. Any soil with PI >35% and swelling potential >10% can be categorized as very high expansive soil, so the expansive soil in the present study has high swelling potential.

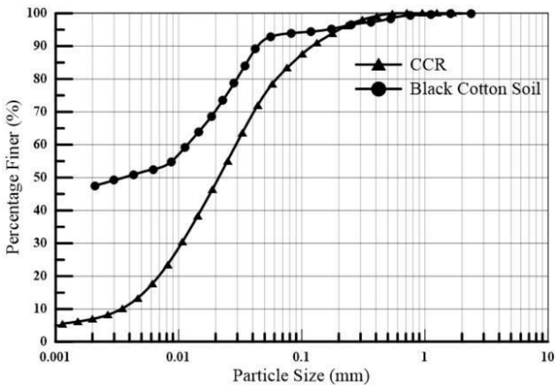


Fig. 2. Particle size distribution curve of expansive soil and CCR.

2.2 Calcium Carbide Residue:

Calcium Carbide Residue (CCR) was obtained from Swastika Industrial gases Pvt. Ltd. Nashik, India. CCR was obtained from the disposal area in dry form in greyish-white color, as shown in figure3. The CCR was oven-dried at 105°C for 24 hours and ground in a Los Angeles abrasion machine. The CCR was passed through a 425-um sieve for further use in experimentation. The specific gravity (Gs) of CCR was 2.25. The chemical compositions of the CCR, as summarized in Table 2. The grain size distribution of CCR is also shown in Fig.2.

(a) (b)

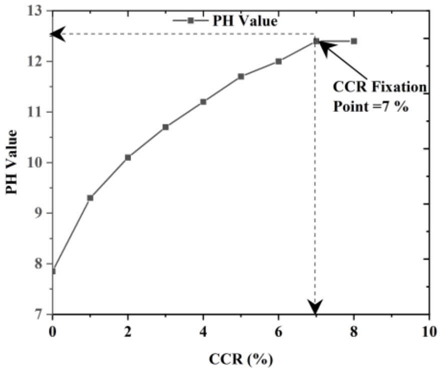
Fig. 3. Disposal of Calcium Carbide Residue: (a) Dry form; (b) Slurry form

Table 2. The Chemical Properties of Expansive Soil and CCR [8]

Chemical Composition (%)	Expansive Soil	CCR
SiO_2	48.50	4.6
Al_2O_3	20.46	0.49
Fe_2O_3	15.73	0.10
CaO	9.60	90
MgO	4.38	0.22
K_2O	3.29	0.002
Na_2O	1.54	0.06
TiO_2	1.48	0.009

3. Experimental Investigation

Experimentation programs to determine the index and engineering properties were car- ried out per Indian standards. CCR sample was added to the soil by weight for differentpercentages (2, 4, 7). Dry samples were mixed thoroughly for proper material mixing, and tests were performed. For identification of the sample, the nomenclature was given, for example, 00BC02 (00 indicates curing days, B-Black Cotton Soil. C – CCR, and 02 is the percentage of CCR added in soil Sample). pH Value and Consistency limits test methods are useful for calculating the optimum dose of CCR)[4,8]. The first method is recommended for lime stabilization, in which a minimum pH value of 12.4 is necessary to initiate the pozzolanic reaction. The pH values measured for soil sample for the var- ious percentage of CCR is shown in figure 4.



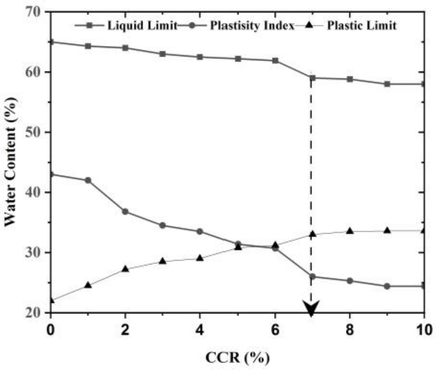


Fig.4. Effect of CCR content on pH value Fig.5.Index Properties of CCR Stabilised Soil

As the CCR content increases, the pH of stabilized clay significantly increases. How- ever, when CCR content is greater than 7%, the pH was observed to be 12.4, and the change in pH was negligible. Thus, this point can be chosen as an optimum percentage of CCR for soil stabilization. The second method is based on consistency limit; figure 5 shows the change in consistency indices of stabilized soil. It was observed that an increase in the percentage of CCR increases the Liquid limit (LL) and decreases the plastic limit (PL) and resulting decrease in the plasticity index (PI). However, the de- crease in PI was minimal after 7% CCR content. Therefore, based on the above two independent methods, 7% CCR content was chosen as the optimum percentage for soil stabilization.

The soil sample was sieved through a 20mm sieve and air-dried for a compaction test. Compaction was carried out using the Standard Proctor test. The compaction for the test consists of the energy derived from a 2.5 kg rammer falling through 30cm onto three layers of soil, each receiving 25 blows. Compaction characteristics, i.e., optimum moisture content (OMC) and maximum dry unit weight (γ_{dry}) for clay stabilized with 7% CCR, were 27.20% and 14.4 kN/m^3. The air-dried clay sample was mixed with various content of CCR (0-8%). The OMC was found to be increased by 3.8%, and γ_{dry} was decreased by 5.2% at an optimum percentage of CCR. It happens because of the cementation property of CCR and the presence of $Ca(OH)_2$. For all tests at each curing time and combination of water content and CCR content, three samples were tested under the same condition to obtain a reliable result.

Table 3. Effect of CCR on γdmax and OMC

% CCR	0	2	4	6	7	8	10
γ_{dmax} (kN/m3)	15.20	15.00	15.40	14.00	14.40	14.20	13.00
OMC (%)	26.00	26.20	26.40	24.00	27.20	28.00	29.00

Differential free swell test performed on each 10gm of soil sample passing from 425um IS sieve. First, pour each soil specimen into a graduated glass cylinder of 100ml capacity filled with water and kerosene. Next, the sample was poured into distilled water and kerosene. Initial readings were recorded, and after 24hrs, final swelling was recorded in both soil samples, and the free swell index was observed.

An unconfined compression strength test was conducted on soil and stabilized soil with varying percentages of CCR by weight of dry soil. Specimens were prepared by mixing the desired proportions of distilled water, soil, and CCR. The soil-CCR mixtures were prepared by first thoroughly mixing dry predetermined quantities. The unconfined compressive strengths were measured in a cylindrical sample, compacted on the optimum dry and wet sides. The required amount of water determined from the compaction curve was later added to the dry mix and compacted. Specimens were cured for 7, 14, and 28 days. The stabilized samples were dismantled from the mold, wrapped in vinyl bags, and stored in a constant temperature humidity chamber (25°C). Specimens were tested, and the failure pattern of the sample was studied, as shown in Figures 6 and 7.

The California Bearing Ratio (CBR) test was carried out in the standard one-dimensional CBR mold. The samples were prepared under the modified Proctor compaction energy and were imposed by a pre-loading pressure. IS 2720: Part 16 (1987) [12] was followed for the sample preparation and testing. The sample was cured for 7, 14, and 28 days. For every reading record, specimen mold was kept in the tank undisturbed for four days. Take the readings of the dial gauge every 24 hrs. and note the time of reading. They have maintained the water level constant in the tank. Took the final reading at the end of 4days. Figure 8 shows the relation between the CBR values of the soil sample.

For all tests at each curing time and combination of water content and CCR content, five samples were tested under the same condition to obtain a reliable result

4. Result & Discussion

The Swelling Index of soil was recorded as 75, and it decreases with the addition of CCR up to 24 % for the optimum dose of CCR, i.e., for the addition of 7%. Lower specific gravity and affinity of CCR towards water decrease swelling index.

Variation of the Unconfined compressive strength (UCS) value of the stabilized soil with the variation of CCR and curing time is shown in figure 6. An increase in the UCS value of soil of about 60% was observed with the addition of 7% CCR for 28 days of curing time. This increase in strength was due to the increase in the cementitious prod- uct in the soil despite its lower dry unit weight [4, 10]. The effect of CCR on strength was observed to be a maximum between 4 to 6%, as shown in figure 6.

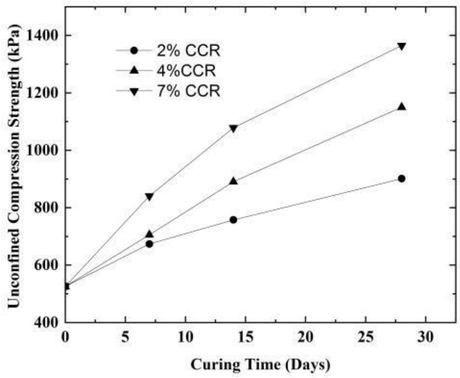


Fig.6 Effect of the addition of CCR on UCS with curing days

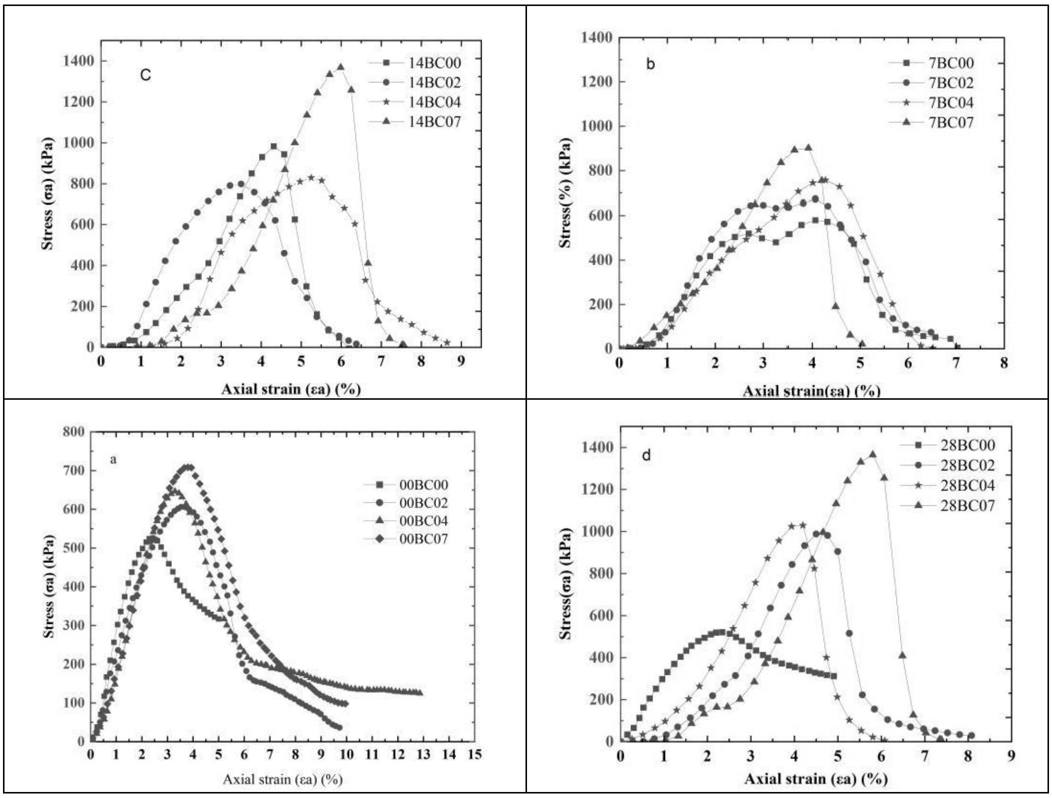


Fig.7 Stress-strain behavior of sample under UCS test for curing of (a) o days (b) 7 days (c) 14 days (d) 28 days

Addition of CCR below 4% and above 7%, the effect on strength gain is minor. The strength development in stabilized soil after 28 days of curing is almost 62 %, with the addition of 7% (optimum dose) of CCR. The compaction improves the effective stresses.California Bearing Ratio (CBR) values were recorded with various curing times and variations in CCR %(2%, 4%,7%) shown in fig 8.

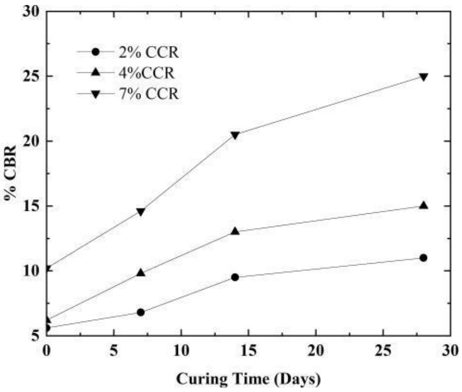


Fig.8 Effect of the addition of CCR on CBR with curing days

The test results show that although the natural soil has low CBR values of 3%, there is an appreciable increase in strength with the addition of CCR in expansive soil. Average peak CBR values of 30% were obtained for 7% CCR admixed with soil by weight of dry soil, beyond which decreases in CBR were recorded. Fig 9 represents the penetration curve of CBR value.

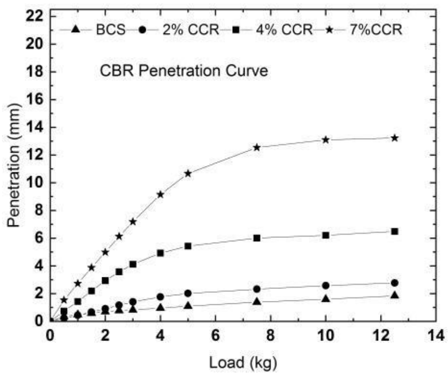


Fig.9. Load-Penetration curve of CBR value

However, since the strength of the subgrade is poor, it is recommended to provide modifications.

IRC 37 [13] Recommendation for The effective subgrade CBR should be more than 5 % for roads estimated to carry more than 450 Commercial Vehicles Per Day (CVPD) (two-way) in the year of construction. In addition, the Sub-base minimum CBR value design should be 6% for all cases[13]. The minimum conventional CBR values subbase according to MORTH[14] guideline is recovered 30.

From the Series of tests conducted to evaluate the effect of CCR on expansive soil, it was observed that the CBR value of soil increases with an increase in the percentage of CCR and curing time. Increased CBR value is up to 7% of CCR, and further addition of CCR gives stability in resulting no further increment in CBR value. Therefore 7 % CCR stabilized soil can be used to improve poor subgrade. Increase with the CCR content; the consumed $Ca(OH)_2$ between 7–28 days.

4. Conclusion

1. The effect of CCR on the geotechnical properties of subgrade soil is investigated and analyzed in this study. The results indicate that the presence of CCR affected the subgrade soil CBR value. However, the CBR value for mixtures had fulfilled the minimum 5% CBR of IRC requirement.

2. The maximum improvement occurred at 7% of CCR, contributing to the highest CBR value. Thus, 7% CCR is recommended to be implemented for subgrade soil stabilization.

3. An increase in the curing period increases the CBR values. However, an increase in CBR value reduces the thickness of sub base. This reduction leads to a reduction in the cost of pavements.

4. The strength of CCR-stabilized clay increases with curing time due to the pozzolanic reaction. For expansive soil studied in this work, the optimum dosage of CCR is 7% by weight of soil.

5. Unconfined Compression Test with varying CCR percentages and for different curing days, it was observed that the UCS of the sample increases with an increase in CCR content. Moreover, UCS also increases with an increase in the duration of curing. For 7% CCR and 28 days of curing, the strength observed is1364 kPa, almost 1.51 times the unconfined compressive strength of expansive soil.

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