Buletin Profesi Insinyur 7(1) (2024) 050–055
http://dx.doi.org/10.20527/bpi.v7i1.254

ISSN 2654-5926

Effect of Calcium Carbide Residue and Salt (NaCl) Addition on Mechanical Properties of Soil

Ulfariansyah[1]**, R.M. Rustamaji**[1]**, Vivi Bachtiar**[1]

[1] Program Studi Teknik Sipil, Universitas Tanjungpura, Pontianak, Indonesia

✉ rustamaji@civil.untan.ac.id

Soils exhibit varied characteristics and properties, with poor-quality soil posing risks to construction integrity. Soil stabilization, typically achieved through chemical means involving additives like Salt (NaCl) and Calcium Carbide Residue (CCR), is employed to mitigate these risks. This study aims to assess the mechanical properties of soil following treatment with 16% NaCl and varying percentages of CCR (5%, 10%, and 20%) over curing periods of 0, 7, and 14 days. Tests included compaction test, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and direct shear. Results revealed the original soil's optimal moisture content of 29%, maximum density of 1.30 gr/cm^3, CBR of 3.2%, UCS of 3.30 kg/cm^2, cohesion of 0.21 kg/cm^2, and internal friction angle of 23.95°. Post-stabilization, a decrease in optimum moisture content was observed, with the lowest reduction in the 16% NaCl-treated soil (20,15%). Maximum density increased most notably in the 16% NaCl and 20% CCR mixture (by 1.38 gr/cm^3). Additionally, CBR, UCS, cohesion, and internal friction angle exhibited the highest enhancements in the 16% NaCl and 20% CCR mixture at 14 days of curing, respectively increasing by 7.83%, 5.91 kg/cm^2, 0.46kg/cm^2, and 48.55°.

Kata kunci: Calcium Carbide Residue (CCR), mechanical properties, NaCl, soil stabilization

Diajukan: 16 Mei 2024
Direvisi: 25 Meii 2024
Diterima: 7 Juni 2024
Dipublikasikan online: 15 Juni 2024

Introduction

Calcium carbide residue has demonstrated potential in soil stabilization applications. Research has investigated its effectiveness in combination with various materials such as fly ash (Horpibulsuk et al., 2012), rice husk ash (Liu et al., 2019), and biomass ash (Vichan & Rachan, 2013). The addition of calcium carbide residue has been shown to improve the compressive strength of soils, particularly in wet-dry cycles (Kampala et al., 2014), and assist in stabilizing expansive clay (Liu et al., 2019). Studies have also examined the impact of calcium carbide residue on the engineering properties of different soil types, including silty clay Kampala & Horpibulsuk (2013) and soft highway subgrade soil (Du et al., 2016; Afzali & Sharma, 2023).

Recent research has focused on utilizing calcium carbide residue as a sustainable stabilization additive (Latifi et al., 2018; Nshimiyimana et al., 2018). It has been recognized as a by-product capable of enhancing the compressive strength of soils (Nshimiyimana et al., 2018). Additionally, incorporating calcium carbide residue has been associated with a reduction in soil swelling (Afzali & Sharma, 2023), making it a valuable resource for addressing soil engineering challenges.

Studies have emphasized the chemical stabilization potential of calcium carbide residue in various soil types, such as clay (Nshimiyimana et al., 2020; Vichan et al., 2013), Bangkok clay (Vichan & Rachan, 2013; Vichan et al., 2013), and residual soil (Yong et al., 2019). The stabilization mechanism involves reactions like ion-exchange, pozzolanic, and carbonation reactions (Han et al., 2021). Furthermore, researchers have explored using calcium carbide residue in combination with materials like mushroom dreg and calcium superphosphate for stabilizing heavy metals in contaminated soils (Wu et al., 2019).

NaCl, or sodium chloride, has been studied for its potential role in soil stabilization. When NaCl is applied to soil, it can mimic the increase in NaCl content that may occur when using produced waters from oil and gas wells for restoration efforts (Chandler et al., 2018). However, it is important to note that high NaCl content can increase the leachability of hazardous components in stabilized soil, which could have implications for environmental impact (Li et al., 2019). On the other hand, the addition of NaCl as a soil stabilizer has been shown to reduce moisture, plasticity index (PI), and increase soil density, indicating its potential for improving soil properties (Sudjianto et al., 2021).

Research has explored the impact of NaCl on the geotechnical characteristics of soils, particularly in semi-arid regions. Studies suggest that NaCl significantly influences the geotechnical properties of soils, highlighting its role in altering soil behavior (Aal et al., 2023). Furthermore, investigations have delved into the effects of NaCl on the microstructural and mechanical properties of alkali-activated cements used for

Cara mensitasi artikel ini:
Ulfariansyah, Rustamaji R.M., Bachtiar V (2024) Effect of Calcium Carbide Residue and Salt (NaCl) Addition on Mechanical Properties of Soil. *Buletin Profesi Insinyur* 7(1). 050-054

stabilizing sandy soils, indicating a potential for NaCl to influence the strength and stability of soil structures (Razeghi & Ghadir, 2022).

Moreover, studies have examined the use of NaCl in combination with other materials like cement for soil stabilization. For example, incorporating NaCl along with CKD in clay soil has shown to reduce energy consumption, e-CO2, and stabilization costs, suggesting a potential cost-effective and environmentally friendly approach to soil stabilization (Canakci, 2022). However, there has been no soil stabilization that combines CCR and NaCl. The aim of this study is to assess the mechanical properties of soil following stabilization using additional materials, namely Calcium Carbide Residue and Salt (NaCl), with various mixture combinations and curing durations.

Materials and Method

Soil and Material Preparation

The soil samples utilized were sourced from the vicinity of the Basic Electronics Laboratory, Faculty of Engineering, Tanjungpura University, Pontianak City. These samples were classified as disturbed soil and were procured using a hoe at an approximate depth of 50 cm from the surface. Subsequently, the soil samples underwent a drying process facilitated by solar heat to preserve their mineral composition. Following drying, the soil was pulverized and sieved using a 4.75 mm mesh sieve.

The salt (NaCl) employed in the study was coarse salt readily available in retail grocery stores. The NaCl was pulverized and sifted through a 2.00 mm sieve to ensure uniformity in particle size.

The Calcium Carbide Residue (CCR) utilized was obtained from the waste generated at the Suara Motor welding workshop located on Jalan Imam Bonjol, Pontianak City, West Kalimantan. The CCR underwent a drying process under sunlight and was then sieved through a 0.85 mm mesh sieve for further refinement.

Determination of NaCl Concentration

Proctor compaction test was conducted to determine the optimal percentage of salt (NaCl) used. The trial for establishing the optimum NaCl percentage commenced at 2% and progressed to 4%, 8%, 16%, and finally 32%. Subsequently, the Proctor compaction test was performed to ascertain the maximum dry density for each NaCl percentage attempted. As referenced in Cahyadi and Puspasari (2020), CBR values exhibit an upward trend following stabilization with Salt (NaCl) at percentages ranging from 10% to 15%.

Determination of CCR Percentage

The selection of percentage variations was based on references from previous studies that also employed CCR as a stabilization material. According to previous research (Ardiansyah et al., 2020), the range of CCR percentages utilized falls between 5% and 20%. Consequently, for this study, the variations in CCR percentages used were 5%, 10%, and 20%.

Mixing Procedures

The mixing process begins after the soil and materials are prepared. Salt (NaCl) is dissolved in water to achieve a predetermined moisture content. Subsequently, the soil is blended with CCR and stirred until homogeneous. The salt solution (NaCl) is then added to the soil-CCR mixture and stirred until uniform. The combined soil mixture is transferred to a plastic bag and left to stand for approximately 5 hours to optimize the reaction between the soil and the stabilizing material.

Variations in Stabilized Soil Mixtures

The stabilized soil mixture with CCR and Salt (NaCl) can be seen in Table 1. The table outlines various soil mixtures and their compositions, along with the corresponding curing periods and codes used in the study. The first entry represents the control group, consisting of soil without any additional admixtures, denoted as "S" and cured for 0 days. The second entry, labeled "SS," comprises 84% soil and 16% salt, with curing periods of 0, 7, and 14 days. The third, fourth, and fifth entries, labeled "SSC-5," "SSC-10," and "SSC-20" respectively, incorporate varying proportions of soil (79%, 74%, and 64% respectively), salt (16% in all cases), and calcium carbide residue (5%, 10%, and 20% respectively). These mixtures are also subjected to curing for 0, 7, and 14 days. This systematic variation allows for the investigation of the effects of salt and calcium carbide residue on the mechanical properties of the soil mixtures over different curing periods.

Table 1. Variations in Natural Soil Mixtures with Calcium Carbide Residue and Salt (NaCl)

No	Mixed Variations	Curing Period (Day)			Code
1	Soil Without Admixture		0		S
2	Soil 84% + Salt 16%	0	7	14	SS
3	Soil 79% + Salt 16% + CCR 5%				SSC-5
4	Soil 74% + Salt 16% + CCR 10%				SSC-10
5	Soil 64% + Salt 16% + CCR 20%				SSC-20

Testing of Soil Mechanical Properties

The soil mechanical properties testing encompassed four main tests: the soil density test, CBR test, UCS test, and direct shear test. The compaction test was prioritized as it determines the optimum water content used in subsequent tests. The testing procedures followed national standard of SNI 1742 2008.

For the soil density test, five specimens were prepared for each mixture variation without a curing period. The CBR test followed national standards of SNI 1744 2012. with one specimen prepared for each mixture variation and cured for 0, 7, and 14 days. Similarly, the UCS test, following national standards of SNI 3638 2012 involved one specimen for each mix variation and curing period, also cured for 0, 7, and 14 days.

The direct shear test, per national standards of SNI 3420 2016, required three specimens for each mix variation and curing period, cured for the same durations.

Results and Discussion

Results and Analysis of Compaction Tests

In this test, the data obtained includes the Maximum Dry Density (MDD) value and the Optimum Moisture Content (OMC) value. The test results are presented in Table 2. The table illustrates the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values for various soil mixtures. The original soil sample, denoted as "S," has an OMC of 29.00% and an MDD of 1.303 g/cm³. When mixed with 16% salt ("SS"), the OMC decreases to 20.15% while the MDD slightly increases to 1.330 g/cm³. Introducing 5% CCR into the mixture ("SSC-5") results in an OMC of 23.00% and an MDD of 1.350 g/cm³. Increasing the CCR content to 10% ("SSC-10") further raises the OMC to 25.50% and the MDD to 1.370 g/cm³. Finally, a 20% CCR content ("SSC-20") yields an OMC of 26.00% and an MDD of 1.375 g/cm³. These values indicate the moisture content and density at which the soils achieved maximum compaction.

Table 2 Compaction Test Results for Unmodified and Stabilized Soil

Samples	OMC (%)	MDD (g/cm³)
S	29.00	1.303
SS	20.15	1.330
SSC-5	23.00	1.350
SSC-10	25.50	1.370
SSC-20	26.00	1.375

The Optimum Moisture Content (OMC) of the original soil is 29.00%. After adding stabilization materials, there is a significant decrease in the SS mixture variation, with a value of 20.15% obtained. This reduction is attributed to the salt ions binding water within the mixture, enhancing the soil's cohesion and reducing water content, thereby increasing soil density. However, upon adding CCR, the water content increases due to the pozzolanic reaction of CCR with the soil. This reaction requires an appropriate water content and can strengthen the soil.

Results and Analysis of CBR Tests

Table 3 presents the California Bearing Ratio (CBR) values for different soil mixtures at varying curing periods. The original soil sample (S) shows a CBR value of 3.196% at 0 days. When mixed with 16% salt (SS), the CBR value increases to 3.391% at 0 days, and further to 3.620% and 3.815% at 7 and 14 days respectively. Introducing 5% CCR into the mixture (SSC-5) results in CBR values of 3.457%, 3.718%, and 4.109% at 0, 7, and 14 days respectively. Increasing the CCR content to 10% (SSC-10) leads to higher CBR values of 5.218%, 5.576%, and 6.750%, while a 20% CCR content (SSC-20) yields even higher CBR values of 5.772%, 6.457%, and 7.826% at 0, 7, and 14 days respectively. These values indicate the load-bearing capacity of the soil mixtures under different curing conditions.

The data presented in this paragraph is likely plotted in a graph in Figure 1, illustrating the relationship between soil mixtures, curing periods, and CBR values. The paragraph describes the California Bearing Ratio (CBR) values for different soil mixtures at various curing periods. It outlines the CBR values of the original soil sample (S) and how they change when mixed with salt (SS) and calcium carbide residue (CCR) at different percentages. The CBR values are presented at 0, 7, and 14 days, showing the increase in load-bearing capacity of the soil mixtures over time.

Table 3 CBR tests result

No	Sample	CBR Value (%)		
		0 Day	7 Day	14 Day
1	S	3.196		
2	SS	3.391	3.620	3.815
3	SSC-5	3.457	3.718	4.109
4	SSC-10	5.218	5.576	6.750
5	SSC-20	5.772	6.457	7.826

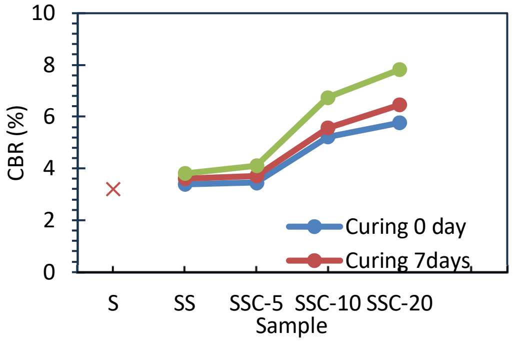

Figure 1 Influence of Stabilization Materials on CBR Test Results

Results and Analysis of UCS Tests

Table 4 presents the Unconfined Compressive Strength (UCS) values for different soil mixtures at various curing periods. The original soil sample (S) shows a UCS value of 3.304 kg/cm² at 0 days. When mixed with 16% salt (SS), the UCS value increases to 3.460 kg/cm² at 0 days, and further to 3.590 kg/cm² and 3.940 kg/cm² at 7 and 14 days respectively. Introducing 5% CCR into the mixture (SSC-5) results in UCS values of 3.527 kg/cm², 3.946 kg/cm², and 4.224 kg/cm² at 0, 7, and 14 days respectively. Increasing the CCR content to 10% (SSC-10) leads to higher UCS values of 3.810 kg/cm², 4.565 kg/cm², and 4.913 kg/cm², while a 20% CCR content (SSC-20) yields even higher UCS values of 4.132 kg/cm², 5.027 kg/cm², and 5.910 kg/cm² at 0, 7, and 14 days respectively. These values indicate the compressive strength of the soil mixtures under different curing conditions.

Table 4 UCS tests result

No	Sample	UCS (kg/cm²)		
		0 Day	7 Day	14 Day
1	S	3.304		
2	SS	3.460	3.590	3.940
3	SSC-5	3.527	3.946	4.224
4	SSC-10	3.810	4.565	4.913
5	SSC-20	4.132	5.027	5.910

The table also translates its data into graphical representations to provide a visual depiction of the trends in Figure 2. The Unconfined Compressive Strength (UCS) values for each soil mixture (S, SS, SSC-5, SSC-10, SSC-20) at 0, 7, and 14 days are graphed to illustrate the changes over time. This visual aid helps in understanding how the addition of stabilizing materials and varying curing periods affect the compressive strength of the soil. The graphs showcase the increasing trend in UCS values with higher percentages of CCR and longer curing periods, offering a comprehensive view of the soil's mechanical behavior and its suitability for various engineering applications.

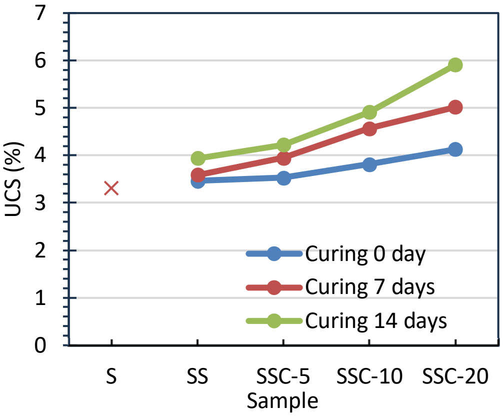

Figure 2 Influence of Stabilization Materials on Unconfined Compressive Strength Test Results

Table 5 shows the results of direct shear test results to all samples. The table presents cohesion values for different soil samples at varying curing periods. The original soil sample (S) exhibits a cohesion of 0.20 kg/cm² at 0 days. Mixing the soil with 16% salt (SS) increases the cohesion to 0.21 kg/cm² at 0 days, further rising to 0.25 kg/cm² and 0.29 kg/cm² at 7 and 14 days, respectively. Introducing 5% calcium carbide residue (CCR) into the mixture (SSC-5) results in cohesion values of 0.24 kg/cm², 0.29 kg/cm², and 0.34 kg/cm² at 0, 7, and 14 days, respectively. Increasing the CCR content to 10% (SSC-10) leads to cohesion values of 0.30 kg/cm², 0.36 kg/cm², and 0.40 kg/cm² at 0, 7, and 14 days, respectively. Finally, a 20% CCR content (SSC-20) yields cohesion values of 0.32 kg/cm², 0.39 kg/cm², and 0.46 kg/cm² at 0, 7, and 14 days, respectively. These results demonstrate the soil's ability to resist shear stress and maintain its integrity over time.

Table 5 also illustrates the internal friction angle (ϕ) values for the soil samples. The original soil sample (S) has internal friction angle values of 23.95°, 27.80°, and 29.19° at 0, 7, and 14 days, respectively. Mixing with 16% salt (SS) increases these values to 24.15°, 28.96°, and 31.15° at 0, 7, and 14 days, respectively. The addition of 5% CCR (SSC-5) further increases the internal friction angle to 25.77°, 33.47°, and 39.78° at 0, 7, and 14 days, respectively. With 10% CCR (SSC-10), the internal friction angle values rise to 28.29°, 38.71°, and 48.55° at 0, 7, and 14 days, respectively. However, in the case of 20% CCR (SSC-20), the internal friction angle values fluctuate, with 34.15° at 0 days, 27.80° at 7 days, and 29.19° at 14 days. These values indicate the soil's ability to resist deformation and provide insights into its stability under different curing conditions.

Table 5 Direct shear tests result

No	Sample	cohesion (kg/cm²)			Internal friction angle (ϕ) (°)		
		0	7	14	0	7	14
1	S	0.20			23.95	27.80	29.19
2	SS	0.21	0.25	0.29	24.15	28.96	31.15
3	SSC-5	0.24	0.29	0.34	25.77	33.47	39.78
4	SSC-10	0.30	0.36	0.4	28.29	38.71	48.55
5	SSC-20	0.32	0.39	0.46	34.15	27.80	29.19

The table not only provides numerical values but also visually represents the data through graphs for a clearer understanding of the trends in Figure 3. The cohesion values for each sample (S, SS, SSC-5, SSC-10, SSC-20) at 0, 7, and 14 days are plotted to show how they change over time. Similarly, the internal friction angle (ϕ) values for the same samples and curing periods are graphed to illustrate the variations in soil behavior under different stabilization conditions. These graphs offer a comprehensive view of the soil's mechanical properties, aiding in the analysis of its stability and strength characteristics.

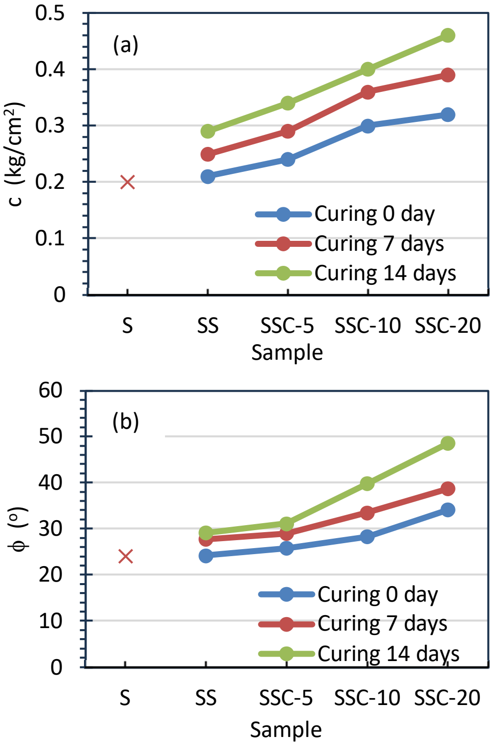

Figure 3 Direct shear test result (a) cohesion, and (b) internal friction angle.

Soil stabilization is a crucial process in civil engineering that aims to enhance the engineering properties of soil for construction purposes. When evaluating the potential use of NaCl and calcium carbide residue (CCR) in soil stabilization, it is important to assess their impact on key soil parameters such as Unconfined Compressive Strength (UCS), California Bearing Ratio (CBR), cohesion, internal friction angle, and compaction.

Research by Jiang et al. (2016) highlights the effectiveness of CCR in stabilizing soft highway subgrade soil. Their study comprehensively evaluates the physical, mechanical, and microstructural properties of soil stabilized with CCR, demonstrating its ability to improve soil characteristics.

Similarly, the study by Blayi et al. (2020) focuses on stabilizing high-plasticity silt using waste brick powder and alkaline activators. This research underscores the importance of conducting UCS tests on stabilized soils, which is pertinent when assessing the impact of NaCl and CCR on soil strength and stability.

Furthermore, Muhardi et al. (2019) investigate peat soil stabilization using lime-cement mixtures, providing valuable insights into selecting suitable stabilizing agents for soil improvement. This study's findings are relevant when considering how CCR may affect soil cohesion and internal friction angle.

Additionally, Schäffer et al. (2008) discuss changes in soil shrinkage due to compaction, emphasizing the significance of soil porosity and compaction in soil stabilization. Understanding how NaCl and CCR influence soil compaction is crucial for evaluating their effectiveness in soil stabilization applications.

Combining NaCl and CCR could potentially enhance these individual effects. For example, the reduction in soil swelling achieved by CCR when combined with polypropylene fiber waste (Afzali & Sharma, 2023) could be complemented by NaCl's ability to reduce moisture content, further improving the overall stability of the soil. Additionally, the increase in compressive strength of soils achieved by CCR (Nshimiyimana et al., 2018) could be enhanced by NaCl's influence on soil density, leading to a more robust and stable soil structure.

However, it's crucial to note that while both NaCl and CCR offer benefits for soil stabilization, there are also potential environmental implications to consider. High NaCl content can increase the leachability of hazardous components in soil (Li et al., 2019), and the sustainable utilization of CCR must be ensured to avoid negative environmental impacts (Latifi et al., 2018).

The combined use of NaCl and CCR in soil stabilization has the potential to enhance soil properties and stability. However, careful consideration must be given to the environmental impacts and the long-term performance of the stabilized soil. Further research and field trials are necessary to fully understand the synergistic effects and optimize the use of these materials in soil stabilization applications.

Conclusion

The compaction tests provided valuable insights into the behavior of the soil mixtures under different stabilization conditions. The Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) values were key indicators of the soil's compaction characteristics. The original soil sample (S) had an OMC of 29.00% and an MDD of 1.303 g/cm³. Upon adding 16% salt (SS), the OMC decreased to 20.15%, indicating improved compaction, while the MDD increased slightly to 1.330 g/cm³. Introducing 5% CCR (SSC-5) resulted in an OMC of 23.00% and an MDD of 1.350 g/cm³. Further increasing the CCR content to 10% (SSC-10) raised the OMC to 25.50% and the MDD to 1.370 g/cm³. Finally, a 20% CCR content (SSC-20) yielded an OMC of 26.00% and an MDD of 1.375 g/cm³. These results indicated the moisture content and density at which the soil achieved maximum compaction.

The CBR tests provided insights into the load-bearing capacity of the soil mixtures under different curing periods. The original soil sample (S) showed a CBR value of 3.196% at 0 days. Mixing with 16% salt (SS) increased the CBR value to 3.391% at 0 days and further to 3.620% and 3.815% at 7 and 14 days, respectively. Introducing 5% CCR (SSC-5) resulted in CBR values of 3.457%, 3.718%, and 4.109% at 0, 7, and 14 days, respectively. Increasing the CCR content to 10% (SSC-10) led to higher CBR values of 5.218%, 5.576%, and 6.750%, while a 20% CCR content (SSC-20) yielded even higher CBR values of 5.772%, 6.457%, and 7.826% at 0, 7, and 14 days, respectively. These results indicated the soil's ability to withstand applied loads and its suitability for construction purposes.

The UCS tests provided valuable data on the compressive strength of the soil mixtures. The original soil sample (S) exhibited a UCS value of 3.304 kg/cm² at 0 days. Mixing with 16% salt (SS) increased the UCS value to 3.460 kg/cm² at 0 days and further to 3.590 kg/cm² and 3.940 kg/cm² at 7 and 14 days, respectively. Introducing 5% CCR (SSC-5) resulted in UCS values of 3.527 kg/cm², 3.946 kg/cm², and 4.224 kg/cm² at 0, 7, and 14 days, respectively. Increasing the CCR content to 10% (SSC-10) led to higher UCS values of 3.810 kg/cm², 4.565 kg/cm², and 4.913 kg/cm², while a 20% CCR content (SSC-20) yielded even higher UCS values of 4.132 kg/cm², 5.027 kg/cm², and 5.910 kg/cm² at 0, 7, and 14 days, respectively. These results indicated the soil's ability to resist compressive stresses and its suitability for use in construction projects.

References

Afzali, M., & Sharma, A. (2023). Sustainable utilization of calcium carbide residue along with polypropylene fiber waste materials for accessing swelling and strength characteristics of black cotton soil. IOP Conference Series Earth and Environmental Science, 1110(1), 012003. https://doi.org/10.1088/1755-1315/1110/1/012003

Aal, A., Abdullah, G., Zakaly, H., Awad, H., Omar, A., Sakr, M., … Ene, A. (2023). Geotechnical aspects of alluvial soils at different depths under sodium chloride action in Najran region, Saudi Arabia: field supported by laboratory tests. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1073718

Blayi, R., Sherwani, A., Ibrahim, H., & Abdullah, S. (2020). Stabilization of high-plasticity silt using waste brick powder. SN Applied Sciences, 2(12). https://doi.org/10.1007/s42452-020-03814-8

Canakci, H. (2022). Assessing the effect of seawater and magnesium sulfate on the durability and strength properties of cement-stabilized full-scale soilcrete column constructed in clayey soil. Arabian Journal for Science and Engineering, 47(10), 13171-13185. https://doi.org/10.1007/s13369-022-06740-6

Chandler, D., Day, N., Madsen, M., & Belnap, J. (2018). Amendments fail to hasten biocrust recovery or soil stability at a disturbed dryland sandy site. Restoration Ecology, 27(2), 289-297. https://doi.org/10.1111/rec.12870

Du, Y., Jiang, N., Liu, S., Horpibulsuk, S., & Arulrajah, A. (2016). Field evaluation of soft highway subgrade soil stabilized with calcium carbide residue. Soils and

Foundations, 56(2), 301-314. https://doi.org/10.1016/j.sandf.2016.02.012

Han, Y., Xia, J., Chang, H., & Xu, J. (2021). The influence mechanism of ettringite crystals and microstructure characteristics on the strength of calcium-based stabilized soil. Materials, 14(6), 1359. https://doi.org/10.3390/ma14061359

Horpibulsuk, S., Phetchuay, C., & Chinkulkijniwat, A. (2012). Soil stabilization by calcium carbide residue and fly ash. Journal of Materials in Civil Engineering, 24(2), 184-193. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000370

Jiang, N., Du, Y., Liu, S., Wei, M., Horpibulsuk, S., & Arulrajah, A. (2016). Multi-scale laboratory evaluation of the physical, mechanical, and microstructural properties of soft highway subgrade soil stabilized with calcium carbide residue. Canadian Geotechnical Journal, 53(3), 373-383. https://doi.org/10.1139/cgj-2015-0245

Kampala, A., & Horpibulsuk, S. (2013). Engineering properties of silty clay stabilized with calcium carbide residue. Journal of Materials in Civil Engineering, 25(5), 632-644. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000618

Kampala, A., Horpibulsuk, S., Prongmanee, N., & Chinkulkijniwat, A. (2014). Influence of wet-dry cycles on compressive strength of calcium carbide residue–fly ash stabilized clay. Journal of Materials in Civil Engineering, 26(4), 633-643. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000853

Latifi, N., Vahedifard, F., Ghazanfari, E., & Rashid, A. (2018). Sustainable usage of calcium carbide residue for stabilization of clays. Journal of Materials in Civil Engineering, 30(6). https://doi.org/10.1061/(ASCE)MT.1943-5533.0002313

Li, X., Zhou, S., Zhou, Y., Min, C., Cao, Z., Du, J., … Shi, Y. (2019). Durability evaluation of phosphogypsum-based cemented backfill through drying-wetting cycles. Minerals, 9(5), 321. https://doi.org/10.3390/min9050321

Liu, Y., Chang, C., Namdar, A., She, Y., Lin, C., Yuan, X., … Qin, Y. (2019). Stabilization of expansive soil using cementing material from rice husk ash and calcium carbide residue. Construction and Building Materials, 221, 1-11. https://doi.org/10.1016/j.conbuildmat.2019.05.157

Nshimiyimana, P., Fagel, N., Messan, A., Wetshondo, D., & Courard, L. (2020). Physico-chemical and mineralogical characterization of clay materials suitable for production of stabilized compressed earth blocks. Construction and Building Materials, 241, 118097. https://doi.org/10.1016/j.conbuildmat.2020.118097

Nshimiyimana, P., Miraucourt, D., Messan, A., & Courard, L. (2018). Calcium carbide residue and rice husk ash for improving the compressive strength of compressed earth blocks. MRS Advances, 3(34-35), 2009-2014. https://doi.org/10.1557/adv.2018.147

Razeghi, H., & Ghadir, P. (2022). Mechanical strength of saline sandy soils stabilized with alkali-activated cements. Sustainability, 14(20), 13669. https://doi.org/10.3390/su142013669

Schäffer, B., Schulin, R., & Boivin, P. (2008). Changes in shrinkage of restored soil caused by compaction beneath heavy agricultural machinery. European Journal of Soil Science, 59(4), 771-783. https://doi.org/10.1111/j.1365-2389.2008.01024.x

Sudjianto, A., Suraji, A., & Susilo, S. (2021). Analysis of soil characteristics on expansive clay stabilization using shell ash. Eastern-European Journal of Enterprise Technologies, 6(6 (114)), 58-64. https://doi.org/10.15587/1729-4061.2021.245533

Vichan, S., & Rachan, R. (2013). Chemical stabilization of soft Bangkok clay using the blend of calcium carbide residue and biomass ash. Soils and Foundations, 53(2), 272-281. https://doi.org/10.1016/j.sandf.2013.02.007

Vichan, S., Rachan, R., & Horpibulsuk, S. (2013). Strength and microstructure development in Bangkok clay stabilized with calcium carbide residue and biomass ash. Scienceasia, 39(2), 186. https://doi.org/10.2306/scienceasia1513-1874.2013.39.186

Wibisono, G., & Harist, F. (2019). Peat soils stabilization using lime-cement mixture to prevent peat fires. MATEC Web of Conferences, 276, 05006. https://doi.org/10.1051/matecconf/201927605006

Wu, L., Nong, J., Dong-mei, Z., & Li, Y. (2019). Effects of an integrated carbide slag-mushroom dreg-calcium superphosphate amendment on the stabilization process of Pb, Cu, Zn and Cd in contaminated soils. Sustainability, 11(18), 4957. https://doi.org/10.3390/su11184957

Yong, L., Perera, S., Syamsir, A., Emmanuel, E., Paul, S., & Anggraini, V. (2019). Stabilization of a residual soil using calcium and magnesium hydroxide nanoparticles: a quick precipitation method. Applied Sciences, 9(20), 4325. https://doi.org/10.3390/app9204325