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CALCIUM CARBIDE RESIDUE MODIFIED BLACK COTTON SOIL AS A LANDFILL LINER IN MUNICIPAL SOLID WASTE CONTAINMENT FACILITY

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Abstract : This study examines the potential of utilizing calcium carbide residue (CCR) to improve the engineering properties of black cotton soil (BCS) for landfill liner applications, addressing concerns related to municipal solid waste (MSW) disposal. By evaluating the impact of CCR addition on soil characteristics such as compaction behavior and hydraulic conductivity, the research aims to create a tighter packed soil structure, essential for effective landfill liners. Through a combination of BCS and CCR, the study seeks to enhance waste containment while promoting CCR recycling. The primary objective is to investigate the feasibility of the soil-CCR blend as a sustainable solution for waste disposal in India's central region. This research fills a gap in understanding the combined utilization of BCS and CCR for landfill purposes, contributing to sustainable waste management practices.

Furthermore, the study observes a stepwise increase in Optimum Moisture Content (OMC) as CCR content rises, indicating improved moisture retention capabilities of the soil-CCR mixture. The higher OMC values correlate with decreased MDD, signifying a trade-off between soil density and moisture content. This phenomenon suggests that CCR addition not only improves soil engineering properties but also influences its moisture behavior, which is vital for long-term stability and performance as a landfill liner.

Moreover, the research anticipates that the incorporation of CCR in BCS will result in a consistent enhancement of shear strength, a critical parameter for landfill liner materials. This improvement in shear strength underscores the potential suitability of the soil-CCR mixture as an effective barrier against the migration of leachate and contaminants, thus minimizing environmental risks associated with waste disposal. Overall, the findings highlight the promising potential of CCR-modified BCS as landfill liners, offering improved engineering properties and environmental benefits. The observed trends in compaction behavior and moisture content signify the positive impact of CCR addition on soil stabilization, paving the way for further research and development in sustainable waste management practices. Future investigations will delve into detailed material mixes to elucidate the extent of enhancement in soil properties and validate the suitability of the soil-CCR mixture for landfill liner applications.

As the Optimum Moisture Content (OMC) increases, the Maximum Dry Density (MDD) decreases with an increase in the percentage of CCR. This study anticipates that adding CCR to BCS will lead to a denser soil structure and potentially lower hydraulic conductivity. Moreover, the soil-CCR mixture is expected to show significant improvement in shear strength, making it suitable for landfill liners. More testing will be done to confirm these results and see how different mixtures perform.

Keywords: CCR modified BCS, landfill liners, Hydraulic conductivity, Index Properties.

I. INTRODUCTION

In today's environmentally conscious era, the issue of disposing of solid waste in our communities has become a significant topic of discussion. Over the past few years, we've noticed occasional increases in both the amount and variety of municipal solid waste (MSW) being thrown away every day. This rise can be attributed to factors such as rapid population growth, urbanization, and industrialization, all of which play pivotal roles in shaping our waste generation patterns. Waste is an inevitable byproduct of human activities that involve using natural resources in various forms. Municipal Solid Wastes (MSWs) encompass the types of waste that individuals find cheaper to dispose of rather than recycle. Consequently, the disposal of MSW stemming from human activities has become a cause for concern, particularly in many developing cities [10].

Every year, the global production of Municipal Solid Waste (MSW) amounts to roughly 2 billion tons, with the majority originating from residential households and certain industries sharing similar waste characteristics. Projections derived from the World Bank Report of 2018 indicate that this annual figure is anticipated to escalate to 3.4 billion tons by the year 2050.

There exist two primary methods for disposing of waste: sanitary landfilling and incineration. However, the potential for secure waste disposal in landfills renders landfilling a viable approach to addressing waste disposal challenges.

Presently, the common practice involves open dumping of waste onto unlined land. Landfills present several issues, including the release of hazardous leachates, soil erosion, and water contamination. Among these concerns, the disposal of Municipal Solid Waste (MSW) in low-lying areas without proper sanitary controls stands out as a significant source of soil and groundwater contamination. When water, whether from rainfall or other sources, interacts with MSW, it generates leachate that can infiltrate soil layers and contaminate groundwater. To mitigate these risks, one effective strategy involves depositing waste in engineered waste repository facilities equipped with hydraulic barriers at both the top and bottom. This method helps to reduce soil and groundwater contamination associated with landfilling practices.

Utilizing an engineered waste repository facility equipped with hydraulic barriers at both the top and bottom serves as an effective means to mitigate soil and groundwater contamination resulting from waste disposal. A crucial component of such facilities is the landfill liner, designed to act as a low-permeability barrier. Positioned beneath engineered landfill sites, the liner serves to retard the migration of leachate, along with its toxic constituents, into underlying aquifers or nearby rivers. This preventive measure is essential for averting the potential irreversible contamination of local waterways and their sediments until the liner deteriorates over time. Nowadays, engineers who work with soil use different methods to make it better for building things like roads, railways, buildings, and waste areas. They do this by changing the soil in ways that make it stronger and more stable. Many experts [1,11,16,19,20] have studied and shown how important it is to improve soil for construction projects. These studies help us understand how modifying soil can make buildings and infrastructure safer and more reliable, whether it's a road, a train track, or a waste containment area.

Over the past few decades, significant amount of research work has focused on improvement of black cotton soils. Many studies have looked into mixing black cotton soil with different materials like lime, cement, bitumen, cement kiln dust, and iron tailings. This mixing is done to make the soil stronger and more suitable for construction projects. Black cotton soil is known for having a low ability to support weight and for swelling and shrinking a lot. Because of these issues, construction projects face challenges. To solve these problems, various methods have been used in the past to improve the soil's engineering properties. These methods include adding cement or using chemicals like lime and cement for stabilization. Researchers have also looked into using industrial by-products to stabilize expansive soils. These by-products include blast furnace slag, fly ash, stone dust, and recycled materials, which help reduce environmental impact. Recently, there has been increased interest in using industrial waste for stabilization purposes, including ground granulated blast furnace slag, cement waste, bagasse ash, and bassanite, as highlighted by studies conducted by experts [1,3,8,11,13,14,15,16,17,20,21].

One of these stabilization techniques can include the utilization of Calcium Carbide Residue (CCR), an industrial by-product produced during the manufacturing of acetylene gas. Chemical stabilization techniques are widely employed to enhance the properties of such soils, and CCR has emerged as a sustainable and viable additive for this purpose. Recent studies, such as those conducted by experts [4,5,6,7] have highlighted the effectiveness of CCR in soil stabilization. This approach not only addresses the challenges associated with soft soils but also offers an environmentally friendly solution by repurposing industrial waste. Thus, exploring the potential of CCR as a stabilization technique holds promise for improving soil conditions in construction projects while promoting sustainable practices.

Calcium carbide residue (CCR) is a waste product generated by the acetylene industry, resulting from the reaction between water and calcium carbide. In countries like India, where there are numerous acetylene gas production units and PVC chemical plants, CCR is produced in large quantities. The formation of CCR can be explained by the chemical equation: $CaC2 + 2H2O \rightarrow C2H2 + Ca(OH)2$. Due to its alkalinity, CCR poses significant environmental challenges and must be properly disposed of. Du et al. and Horpibulsuk et al. have highlighted the environmental pollution caused by extensive CCR dumps and recommended the utilization of CCR for ground modification as a low-carbon and low-energy-intensive environmentally friendly technique.

Kumpala and Horpibulsuk [4] conducted a study comparing the effectiveness of Calcium Carbide Residue (CCR) stabilization to lime stabilization from engineering and environmental perspectives. Their findings suggest that CCR stabilization outperforms lime stabilization in terms of both engineering and environmental considerations. One notable aspect is the gradual increase in shear strength observed in CCR-stabilized clay over time. This enhancement is primarily attributed to the pozzolanic reaction occurring within the soil. Overall, their research highlights the promising potential of CCR stabilization as a sustainable and effective method for improving the engineering properties of clay soils while minimizing environmental impact.

This study aims to investigate the fundamental and engineering characteristics of clay stabilized with calcium carbide residue (CCR) to assess its potential suitability as backfill and subbase materials. The basic properties under examination include specific gravity, grain size distribution, and index properties, while the engineering properties encompass compaction behavior, optimum moisture content, consistency limits, hydraulic conductivity, and strength development. Additionally, scanning electron microscopy (SEM) will be utilized to analyze the microstructure of CCR-modified black cotton soil. Given the limited existing research on the impact of calcium carbide residue on black cotton soil as a barrier material, this research fills a significant gap in knowledge. Therefore, the primary focus of this study is to investigate the engineering properties and design criteria of the black cotton soil-CCR mixture for its potential application as hydraulic barriers in waste containment facilities.

Sope of Study

The central region of India boasts abundant stores of black cotton soil, offering a promising avenue for augmenting its characteristics through the incorporation of CCR, thereby creating a formidable hydraulic barrier. This initiative not only confronts the pressing issues of waste management but also catalyzes the extensive repurposing of CCR. The principal objective of this research endeavor is to explore the practical application of the adapted soil-CCR blend as a dependable landfill liner for waste containment facilities. By investigating the effectiveness and feasibility of deploying this composite material, the study endeavors to contribute to sustainable waste disposal practices in the region.

Research gap

Despite the abundance of black cotton soil and the availability of CCR, there exists a notable gap in understanding how the amalgamation of these materials can be optimized for landfill liner applications. Previous studies have primarily focused on individual material characteristics and stabilization techniques, but there is a dearth of research concerning their combined utilization specifically for landfill purposes. Consequently, there is a critical need to bridge this gap by examining the engineering properties, environmental implications, and long-term performance of the soil-CCR composite as a landfill liner, thus providing valuable insights into sustainable waste management practices in the central region of India.

Materials and Methods

1.1 Materials

Black Cotton Soil: A natural disturbed soil sample was collected from the Nashik region in Maharashtra, India. The location is part of the area covered by the expansive soil commonalty known as black cotton soils of central India. The soil's natural water content was measured at 34%, while the hygroscopic moisture content ranged from 8% to 9%. Analysis of the soil sample's grain size distribution, , revealed it to consist of 8% sand, 44% silt, and 48% clay. The soil's specific gravity was determined to be 2.68 respectively. According to the Unified Soil Classification System, the soil was classified as clay with high plasticity (CH). The free swell ratio was calculated by comparing the equilibrium sediment volume of 10gm of oven-dried soil passing through a 425 µm sieve in distilled water to that in kerosene, resulting in a ratio of 1.55. Based on the FSR, the soil was classified as Montmorillonite with moderate expansivity. Table 1 provides details on the chemical composition of the soil sample, indicating high levels of SiO2, Al2O3, and Fe2O3 conducive to the pozzolanic reaction.

Calcium Carbide Residue

Calcium Carbide Residue, a grayish-white powder, was sourced from Swasti-ka Industrial Gas Manufacturing Pvt. Ltd. in Nashik, India. The CCR was collected in dry form from the disposal area. To prepare it for experimentation, the CCR underwent oven-drying at 105°C for 24 hours and was subsequently ground using a Los Angeles abrasion machine. After grinding, the CCR was sieved through a 425 µm sieve for further use in the experiments. The specific gravity (Gs) of the CCR was measured to be 2.30. Table 1 provides details on the chemical composition of the CCR. The high content of CaO (90%) and other pozzolanic materials such as SiO2, Al2O3, and Fe2O3 suggest that the CCR is suitable for producing cementitious materials.

1.2 Classification of soil sample

In line with the experimental procedure, a series of laboratory tests were conducted on the soil sample to assess its index properties. These tests included determining the natural moisture content (NMC), particle size distribution, liquid limit (LL), plastic limit (PL), and specific gravity (Gs). The results of these tests were then used to classify the soil sample according to the Unified Soil Classification System (USCS) as defined by ASTM (1992) and the American Association of State Highway and Transportation Officials (AASHTO) system of soil classification established in 1986.

1.3 Compaction

The specimens were prepared according to the Indian Standard Equivalent of the Modified Proctor Test, which corresponds to the heavy compaction test (IS: 2720 Part VIII - 1983). This procedure was followed meticulously to conduct the Modified Proctor test (MP). The MP method was employed in the compaction test of specimens at various percentages of Calcium Carbide Residue (CCR).

1.4 Hydraulic Conductivity

The falling head test procedure was conducted in accordance with IS: 2720 (Part 17 - 1986). Specimens were compacted in a rigid-wall compaction mould permeameter, and hydraulic permeation tests were performed using the falling head technique described by Head (1992). Following compaction, the specimens and compaction mould were immersed in a tank of water for a minimum of 48 hours to ensure saturation, with the surface of the compacted specimen submerged below the water level. Subsequently, the sample was connected to a standpipe containing distilled water to establish a hydraulic head and facilitate flow measurement. Readings of the change in hydraulic head over time intervals (t, in hours) were consistently recorded. Each flow test was terminated when the flow rates approached within 10% of the average or when a steady-state condition was achieved.

The hydraulic conductivity (k) was determined using Equation (1):

$$\mathbf{k = 2.3\,\frac{al}{At}\log_{10}\frac{h1}{h2}}$$

Where:

k = hydraulic conductivity a= cross-sectional area of the standpipe

l= length of the sample A= cross-sectional area of the sample

h_1 = head at time $t_1 h_{2=}$ head at time, t_2

1.5 Microstructural composition

Microstructural composition analysis of the specimens was conducted using a scanning electron microscope (SEM) for both natural soil samples and optimally treated specimens. SEM is widely utilized for examining the microstructural features of soil, providing insights into the size, shape, arrangement, and composition of soil grains.

Results and Discussion

1.6 Index properties

Table 2 summarizes the properties of the natural soil.

Table 2. Index Properties of the disturbed soil sample

Property	Quantity
Gs	2.30
LL	43.05 %
PL	25.31 %
PI	17.74 %
OMC-MP	15 %
MDD-MP	1.74 Mg/m^3
Colour	Dark Grey
Dominant Clay Mineral	Montmorillonite

1.7 Particle Size Analysis

Soil collected from the landfill site had particle size distribution of 7.5% gravel, 19.2% of sand, 73.3% of silt and clay. The IS Code referred is IS 2720 (Part 4)-1985.

1.8 Specific Gravity

The table represents the specific gravity values for three different materials: Black Cotton Soil (BCS), Calcium Carbide Residue (CCR), and BCS amended with 8% CCR.

Table 3. Specific Gravity

SR.NO.	MATERIAL	SPECIFIC GRAVITY
1	Black Cotton Soil	2.42
2	Calcium Carbide Residue	2.28
3	BCS+ 8%CCR	2.40

The specific gravity of BCS amended with 8% CCR is recorded as 2.40. This value lies between the specific gravity values of pure BCS and pure CCR. The specific gravity of the amended soil reflects the combined characteristics of both components. The decrease in specific gravity compared to pure BCS suggests that the addition of CCR may introduce less dense materials or void spaces into the soil matrix. This could be due to the physical properties of CCR or the effects of mixing and compaction.

1.9 Atterberg's Limit

As the CCR concentration rises, the plastic limit rises and the liquid limit falls, resulting in a drop in the plasticity index. According to past research papers published, the optimum percentage of CCR to be added is 6% to 8%. It was also discovered that adding further then 10% CCR resulted in the smallest change in plasticity index.

1.10 Compaction

1.10.1 Maximum Dry density (MDD)

The addition of Calcium Carbide Residue (CCR) at various percentages (2%, 4%, 6%, and 8% by mass of dry soil) resulted in changes in the Maximum Dry Density (MDD) values. It was observed that the MDD gradually decreased with increasing CCR content for the Modified Proctor (MP) compaction effort. This trend continued until reaching a peak at 8% CCR content.

The decrease in Maximum Dry Density (MDD) can be attributed to two main factors: the lower specific gravity of Calcium Carbide Residue (CCR) and the rapid formation of cementitious products upon its addition. The lower specific gravity of CCR compared to soil particles leads to a reduction in the overall density of the soil mixture. Additionally, the interaction between CCR and other components in the soil triggers the formation of cementitious products, which can further decrease the density of the soil mixture. These combined effects result in a reduction in MDD values as the percentage of CCR increases.

1.10.2 Optimum Moisture Content

Increasing the Calcium Carbide Residue (CCR) content by 2%, 4%, 6%, and 8% during the Modified Proctor (MP) compaction effort resulted in a stepwise increase in Optimum Moisture Content (OMC) values. This trend continued until reaching its maximum at 8% CCR admixture. Specifically, there was an increase in the OMC value observed at 4% CCR content, followed by a further rise up to 8% CCR content. Overall, during the Modified Proctor test, it was observed that the OMC tends to increase with the rising CCR content.

SR.NO.	CCR Percentage	MDD (g/cc)	OMC (%)
1	BCS + 0% CCR	1.520	23.75
2	BCS + 2% CCR	1.500	25.25
3	BCS + 4% CCR	1.470	27.50
4	BCS + 6% CCR	1.440	28.25
5	BCS + 8% CCR	1.420	29.50

Overall, during the Standard Proctor test, it was observed that the OMC tends to increase with the rising CCR content.

1.11 Volumetric Shrinkage

Volumetric shrinkage refers to the decrease in volume of soil mass due to various factors such as drying, compaction, or changes in composition. As the volumetric shrinkage increases with the addition of CCR, it suggests that the soil mass is experiencing greater volume reduction under the same conditions. At 0% CCR content, the BCS exhibited a volumetric shrinkage of 14.73%, which increased progressively with the addition of CCR. The volumetric shrinkage values for BCS amended with 2%, 4%, 6%, and 8% CCR were measured at 15.57%, 16.52%, 17.94%, and 19.18%, respectively. This increase in shrinkage percentage from 14.73% at 0% CCR to 19.18% at 8% CCR indicates a decrease in volumetric shear strength, as the soil becomes more susceptible to volume changes and deformation.

1.12 Direct Shear Strength

The direct shear test performed on the Soil and Soil amended with 2%, 4%, 6% and 8% CCR. The soil shows the larger cohesion and friction angle values of 0.20 kg/cm2 and 5° at 8% CCR amended BCS, respectively.

SR.NO.	CCR Percentage	Undrained Cohesion (Kg/cm2)	Angle of Shearing Resistance (ϕ)
1	BCS + 0% CCR	0.08	13o
2	BCS + 2% CCR	0.11	11o
3	BCS + 4% CCR	0.14	9o
4	BCS + 6% CCR	0.18	7o
5	BCS + 8% CCR	0.20	5o

A decrease in the angle of friction and an increase in cohesion imply a change in the soil's shear strength characteristics towards a more cohesive behaviour. For instance, the undrained cohesion increases from 0.08 kg/cm² for BCS with 0% CCR to 0.20 kg/cm² for BCS with 8% CCR, while the angle of shearing resistance decreases from 13° to 5° over the same range of CCR content. This trend suggests that CCR addition leads to a weakening of the soil's shear strength characteristics.

It can be clearly observed that with increase in percentage of CCR added to soil there is considerable increase in the shear strength of soil, with 8% CCR giving maximum shear strength of 0.20 kg/sq.cm.

Conclusion

1. The particle size distribution analysis reveals the composition of the soil from the landfill site, emphasizing the predominance of fine-grained fractions such as silt and clay.
2. After conducting numerous experiments, it was observed that a 7% addition of CCR led to the most substantial decrease in the soil's plasticity index, thereby reducing its sensitivity to variations in moisture content.
3. When CCR interacts with the soil, it creates cement-like substances that make the soil less dense. This causes the Maximum Dry Density (MDD) values to decrease as more CCR is added. Additionally, during the Standard Proctor test, it was noticed that the Optimum Moisture Content (OMC) tends to go up as the amount of CCR increases.
4. As more CCR is added to BCS, the soil's volume shrinkage increases. For instance, when no CCR is added, the shrinkage is 14.73%, but with 8% CCR, it rises to 19.18%. This suggests that the soil becomes more vulnerable to volume changes and deformation as the CCR content increases.
5. Adding more CCR to the soil significantly boosts its shear strength. Specifically, at 8% CCR, the soil exhibits the highest shear strength, reaching 0.20 kg/sq.cm.

References

Afrin H A Review on Different Types Soil Stabilization Techniques. Int J Transp Eng Technol 3:19–24. (2017).

Ahmed A, Ugai K Cold Regions Science and Technology Environmental effects on durability of soil stabilized with recycled gypsum. (2011).

C.C.Ikeagwuani, I.N.Obeta.: Stabilization of black cotton soil subgrade using sawdust ash and lime, soils and foundation J , science direct elsevier (2019).

David E Daniel.: Case Histories of compacted clay liners and covers for waste disposal facilities, Int. Conference on case histories in geotechnical engineering 1993,S&T Scholars MineAuthor (1993).

Horpibulsuk S, Kampala A, Phetchuay C, Udomchai A, Arulrajah A Calcium Carbide Residue - A Cementing Agent for Sustainable Soil Stabilization. (2015).

Horpibulsuk S, Phetchuay C, Chinkulkijniwat A Soil Stabilization by Calcium Carbide Residue and Soil Stabilization by Calcium Carbide Residue and Fly Ash. J Mater Civ Eng 24:184–193. (2012).

Hrithik Nath.: Geotechnical properties and applicability of bentonite-modified local soil as landfill and environmental sustainability liners, Environmental and sustainability Indicators J, Science direct elsevier (2023).

K.A.Kolekar, T. Hazra.: A review on prediction of municipal solid waste generation models, Int Conference on solid waste management, 51conSWM , elsevier (2015).

K.A.Adeyoma,G.H.Yunusa.: Cassava peel ash modified black cotton soil as material for hydraulic barriers in municipal solid waste containment facility. Cleaner waste system J,Science Direct (2022).

Karanbir singh randhawa, Rajiv chauhan.: An investigation on the effect of lime addition on UCS of Indian black cotton soil, materials today:proceedings J, science direct elsevier (2021).

Kenji watanabe, Susumu nakajima.: Construction and field measurement of high-speed railway test embankment built on Indian expansive soil "black cotton soil", soils and foundations 61 (2021) 218-238 J, elsevier (2021).

Li Liu, Annan Zhou.: Strength performance of cement/slag-based stabilizes soft clays, construction and building materials 211(2019) 909-918 J, scince direct (2019).

Nayseang sun, Supachary chungpaibilpatana.: Development of an appropriate model for forecasting municipal solid waste generation in bangkok, energy procedia 138(2017) 907-912 J, science direct elsevier (2017).

R.K.Etim, A.O.Eberemu.: Stabilization of black cotton soil with lime and iron ore tailings admixture, transportation geotechnics J , scince direct elsevier (2017).

Songsuda vichan, Runglawan rachan.: Chemical stabilization of soft bangkok clay using the blend of calcium carbide residue and biomass ash, Soils and Foundations J, scince direct elsevier (2013).

Suksun Horpibulsuk, Phetchuay.: Strength development in silty clay stabilized with calcium carbide residue and fly ash Soils and Foundation J,Science Direct (2013).

Takeshi kamei, Aly ahmed.: Durability of soft clay soil stabilized with recycled basanite and furnace cement mixtures, soils and foundations J, science direct elsevier (2013).

T. Anstey vathani, J. logeshwari.: A novel approach to utilize recycled concrete aggregates as landfill liner, waste management Bulletin J, scince diect elsevier (2023).

Venkatesh Noolu, heeralal Mudavath .: Permanent behaviour of black cotton soil treated with calcium carbide residue, construction and building materials 223(2019) 441-449 J, scince direct elsevier (2019).

Vinayak kaushal, Dr.S.P.Guleria.: Geotechnical investigation of black cotton soils, Int J of advances in engineering sciences Vol.5, Issue 2, April, (2015).

Yun-jun Du, Ning-Jun Jiang.: Field evaluation of soft highway subgrade soil stabilized with calcium carbide residue, Soils and Foundations J, elseveir (2016).