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Mine Tailing as a Resource for Expansive Soil Stabilization: A Sustainable Perspective in Mining and Mineral Engineering

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Abstract

This study investigates the stabilization of Black Cotton (BC) soil, an expansive and highly compressible soil type unsuitable for construction, through the incorporation of industrial waste materials. Rapid industrialization has escalated the generation of waste by-products, prompting the need for sustainable disposal solutions. This research explores the enhancement of BC soil's properties by reinforcing it with mine tailings (a by-product of the gold extraction process) and lime. BC soil samples were stabilized with mine tailings at varying proportions, from 10% to 50%, with an additional 4% lime [$Ca(OH)_2$] in select combinations. The index and engineering properties of BC soil, mine tailings, and BC-mine tailings-lime mixtures were assessed. Experimental evaluations were conducted for a prolonged curing periods of 0, 7, 14, 30, 60, 90, 180, and 365 days which is the major research gap identified with the literature survey. Scanning Electron Microscopy (SEM) analysis was performed on optimal combinations to observe microstructural changes. The experimental findings indicate a significant improvement in the geotechnical properties of BC soil with the addition of mine tailings and lime, providing a viable approach to both soil stabilization and mine tailing utilization.

Major Findings: *The study found that incorporating mine tailings (10-50 %) and 4% lime significantly improved the geotechnical properties of Black Cotton soil. Prolonged curing (up to 365 days) resulted in enhanced strength and reduced expansiveness, addressing a key research gap. SEM analysis revealed microstructural changes that contributed to the stabilization process.*

Keywords: *Black Cotton Soil (BC Soil), Mine Tailing (MT), Scanning Electron Microscope (SEM)*

1.0 Introduction

Population growth need infrastructure as a basic facility. All construction activity depends mainly on nature of soil and its strength capacity. when soil is poor, it is required to enhance the quality of the soil instead of designing deep and advanced foundations, which is not economical for the society.

BC soil is an expansive soil of clay type which has the mineral montmorillonite, it expands when water comes in contact with soil and contracts when water evaporates. soil expands during rainy season because of the water absorption and contract during the summer. Damages occur in structures as cracks on this type of soil. Black cotton soil has very low resistance and it suffers an excessive change in the volume which makes their use in construction very difficult.

In India expansive soils occupies about $0.8X10^6$ km^2 that is more than 20% of the total area. This soil can cause damage to the structures especially to

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the buildings which are lighter compared to other structures. In many situations expansive soils cannot be used as construction material. Hence to use these soils, property of the BC soil has to be enhanced. Here attempt is made to enhance the property of BC soil by additives like Kolar gold mine tailing and lime. BC soil is generally considered weak soil and causes damages to the structure because of its expansion and high compression property.

Meanwhile Rapid industrialization has exacerbated the challenge of waste disposal. The industrialization has increased the quantity of waste and disposal of waste which is problematic and need concern towards it. Many researches are done on utilizing the waste materials and concentrating the feasibility and environmental suitability[1-17]. MT is a waste by-product from the industry that is generated during the extraction of mineral from mined ores. Disposal and management of MT is one of the important environmental issues of any mining industry during its project life, because mine tailings dump releases fine particles in to atmosphere in the form of dust which causes air pollution due to silty nature of fine particles. Gully erosion is also occurred on the surface of mine tailings dumps during rainy season it affect the nearby agricultural land and pollute the both surface and underground water sources. In order to reduce the disposal problems and the environmental[6] hazards, attempt has been made to use MT in improving the properties of BC soil. Stabilization is one of the known methods to minimize the hazards effect and to prevent the uncontrolled release of MT particles in to the environment[7]. In the above concept, mine tailings is a waste industrial byproduct which is used to alter and enhance the soil properties by adding some additives. Here an attempt was made to stabilize BC soil using mine tailing and lime to form the soil durable and resistant.

2.0 Materials Used

2.1 BC Soil

BC soil is an expansive soil they are mainly found in India's north western region which is called as Deccan plateau region. They are commonly found in Gujrat, Madhya Pradesh, Karnataka and Maharashtra. It takes more than 20% of the total land of the country. Black soil is very favourable to grow cotton so they are called BC soil. It consists many minerals such as montmorillonite

Table 1. Geotechnical property of bc soil and mine tailing

Sl No	**Properties**	**Bc Soil**	**Mine Tailing**
1	Colour	Black	Pale Grey
2	Specific Gravity	2.53	2.72
3	Clay (%)	79.43	12.6
4	Silt (%)	5.01	70.4
5	Sand (%)	5.30	17
6	Gravel (%)	10.26	-
7	Liquid Limit (LL) (%)	51.5	49.5
8	Plastic Limit (PL) (%)	37.2	22.6
9	Plasticity Index (PI) (%)	14.3	26.9
10	MDD in (KN/m^3)	15.60	15.2
11	OMC in (%)	23.05	20
12	UCS in KPa	40.07	46

(shows swelling and shrinkage behavior), magnesium, iron, etc. In the current investigation, soil sample is collected from Davangere District, Karnataka State, India. The sample of BC soil is as given in Figure 1 and the property of BC soil is given in the Table 2.

2.2 Mine Tailings

MT is an industrial waste by-product which is formed in the mining industry after the extraction of minerals from mined ores, which is the range of size from clay to fine sand. The mine tailing is stored in the mine sites. In the study, investigation has been made on the mine tailings obtained from Kolar Gold Fields (KGF) about 85 km from Bangalore, Karnataka state, India. The MT is air dried, powdered and sieved through 425-micron BIS sieve before used for the experiments.

2.3 Lime [Ca (OH)2]

Lime improves the binding property of the soil. Hydrated lime i.e. [Ca (OH)2] is the most commonly used lime during stabilization process. Figure 3 shows the sample of hydrated lime used in the current study. In the current study, lime is obtained from the Nice Chemicals private Ltd, Kochi, Kerala State, India.

In the study 4% lime is taken as optimum percentage with the combination. 4% lime is obtained from the experimental investigation done by finding LL with BC soil by varying 1-8 % lime.

3.0 Methodology

The experiments are conducted on BC soil treating it with MT and lime. Experimental work is grouped into 2 combinations i.e. BC SOIL+MT (varying with 10 to 50 percent) and BC SOIL +MT (varying with 10 to 50 percent) +4% Lime. Both combinations contain MT content which is added with the increments of 10% to 50% by weight of soil. 4% lime is taken as optimum is mixed to the weight of the BC soil. The experiments include specific gravity, Atterberg's limit, compaction test and UCS test. All the experiments are carried according to Indian standard codes and procedures. The SEM and EDX analysis for the combination with highest strength are analysed.

4.0 Experimental Results

4.1 Specific Gravity

Specific gravity[18] of B C Soil is 2.53. Adding of varying percentage of mine tailings to B C Soil, specific gravity improves with increase in mine tailing percentage. This is attributed to heavy mass and density of mine tailing is replaced with lower density of BC Soil compare to mine tailings alone resulted in increase of SG. Adding of optimum lime to BC Soil, the SG decreases. This is because of the presence of lower density of lime which interacts with the soil particle leading to decrease in the SG.

Table 2. SG of BC soil and MT mixtures treated with lime

Mixtures	Specific Gravity
BC Soil alone	2.53
MT alone	2.78
BC SOIL + 10% MT	2.71
BC SOIL + 20% MT	2.71
BC SOIL + 30% MT	2.72
BC SOIL + 40% MT	2.73
BC SOIL + 50% MT	2.74
BC SOIL + 10% MT+ 4%LM	2.70
BC SOIL + 20% MT+ 4%LM	2.69
BC SOIL + 30% MT+ 4%LM	2.69
BC SOIL + 40% MT+ 4%LM	2.68
BC SOIL + 50% MT+ 4%LM	2.67

4.2 Liquid Limit (LL)

Liquid limit test[19,20] is carried on B C Soil with the adding of varying percentage of mine tailings. The LL of BC Soil and mine tailing alone are found to be 58.4% and 34% respectively. Addition of 10% of mine tailing to BC Soil liquid limit reduces to 47.01% on immediate test. Decrease in the LL is because of the reduction with the thickness of diffused double layer which leads to the

Table 3. LL of BCS and MT mixtures with curing

Mixtures	LL (%)			
	Curing period in days			
	0	7	14	30
BC SOIL alone	58.4	-	-	-
MT alone	49.5	48.1	47.7	47.5
BC SOIL+10%MT	47.01	46.5	46.2	45.4
BC SOIL+20%MT	45.80	45.2	46.4	45.1
BC SOIL+30%MT	44.80	41.1	45.7	42.7
BC SOIL+40%MT	43.78	43.9	42.8	42.3
BC SOIL+50%MT	43.21	42.3	45.3	44.9
BC SOIL +10%MT+4% LIME	40.91	40.4	40.1	39.3
BC SOIL +20%MT+4% LIME	39.7	39.1	40.3	39
BC SOIL +30%MT+4% LIME	38.7	35	39.6	36.6
BC SOIL +40%MT+4% LIME	37.68	37.8	36.7	36.2
BC SOIL +50%MT+4% LIME	37.11	36.2	39.2	38.8

reduction in the water holding capacity[21]. This is because the replacement of fine-grained BC Soil with silty and coarse-grained nature of the mine tailing, which makes the mixture more frictional. With the increase in curing period the LL of B C Soil decreases with the increase in the percentage of mine tailing up to 50%, this is because of the reduction in the flocculation leads to the decrease of the entrapped water in the large void spaces of flocculated structure[22]. The effect of flocculation gradually decreases with the increase in the percentage of mine tailing.

4.3 Plastic Limit (PL)

The PL of B C Soil is found to be 30.1%, addition of 10% mine tailing to B C Soil, the PL decreases to 22.01% on immediate testing. Further, PL of B C Soil continuously reduces with the raise in the percentage of mine tailings up to 50%. The reduction in the PL is because of the depression of diffused double layer thickness and consequent aggregation of particles. The PL of B C soil and mine tailings mixture increases with the raise in the curing period, this is because of the increase in flocculation and entrapped water in the large void spaces of flocculated structure. The results of PL for different percentage of mine tailing at various curing has been presented in Table 4.

4.4 Shrinkage Limit (SL)

The SL of BC Soil is found to be 8.40%. Addition of 10% mine tailings to B C Soil the SL increases to 16.2% and it further increases to 18.4% with increase in mine tailing's percentage up to 50% at immediate testing. The raise in SL value with the adding of mine tailing is mainly due to an expansion of the thickness of the diffused double layer[23]. With increase in curing periods, the SL of B C soil treated with different percentage of mine tailings increases. This is because of the effect of flocculation gradually improves with the increase in the percentage of mine tailing because of increasing effect of dilution and hence increased the SL. The result of SL for different percentage of mine tailing at different curing has been presented in Table 5.

4.5 Compaction

Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of B C Soil is 15.8 kN/m^3 and 25.9%

Table 4. PL of BCS and MT mixtures with curing

Mixtures	PL (%)			
	Curing period in days			
	0	7	14	30
BC SOIL alone	30.1	-	-	-
MT alone	22.6	-	-	-
BC SOIL+10%MT	22.01	23.2	23.5	23.6
BC SOIL+20%MT	21.50	21.4	22.2	22.7
BC SOIL+30%MT	20.80	20.4	21.4	21.8
BC SOIL+40%MT	19.93	19.82	20.0	21.0
BC SOIL+50%MT	19.23	18.6	18.8	19.2
BC SOIL +10%MT+4% LIME	29.51	30.7	31	31.1
BC SOIL +20%MT+4% LIME	29	28.9	29.7	30.2
BC SOIL +30%MT+4% LIME	28.3	27.9	28.9	29.3
BC SOIL +40%MT+4% LIME	27.43	27.32	27.5	28.5
BC SOIL +50%MT+4% LIME	26.73	26.1	26.3	26.7

Table 5. SL of B C soil and MT mixtures for varying curing periods

Mixtures	SL			
	Curing period in days			
	0	7	14	30
BCS alone	8.4	-	-	-
MT alone	24.43	26.53	35.53	26.93
BCS+10%MT	16.2	16.6	18.1	18.5
BCS+20%MT	16.5	17.6	18.3	19.2
BCS+30%MT	16.8	18.4	19.5	20.7
BCS+40%MT	17.3	19.4	20.7	23.8
BCS+50%MT	18.4	22.0	23.5	27.1

respectively. Addition of 10% mine tailings to B C Soil MDD marginally increases to 16.3 kN/m^3 and OMC reduces to 24.3%. Further adding of mine tailings to B C Soil at different percentages, MDD increases and OMC decreases. This is due to the decrease in repulsive pressure of soil, which opposes the compact effort. Consequently, soil particles become closer and increase is observed in spite of higher SG of mine tailing. Thus, the decrease in void ratio would be much more reflected in the increase of MDD. The OMC gradually reduces with decrease in repulsive pressure and due to addition of mine tailings with lower water adsorption capacity, OMC of mixture

decreases[24]. The variation of MDD and OMC of B C soil mixed with varying percentage of mine tailing are as given in the Table 6.

Table 6. Compaction characteristics of B C soil added with varying percentage of MT

Mixtures	MDD (kN/m³)	OMC (%)
BCS alone	15.8	25.9
MT alone	15.2	21.5
BCS + 10% MT	16.3	24.3
BCS + 20% MT	15.8	24
BCS + 30% MT	17.1	23.9
BCS + 40% MT	17.3	23.8
BCS + 50% MT	17.2	23.3

4.5.1 Effect of Mt and Lime on Compaction Characters of B C Soil

The MDD and OMC of B C Soil is 15.8 kN/m³ and 25.9% respectively. Addition of 10% mine tailings and optimum lime percent to B C Soil, MDD increases to 16.5kN/m³ with decrease in OMC to 24%. Further increase in mine tailing percentage the MDD increases with marginal increase in OMC. Increase in both MDD and OMC is attributed to the flocculation of soil clay particles which resist the compact effort[25] and the raise in OMC is probably a consequence of the additional water held in the flocculent soil structure resulting in increasing in moisture content is given in the Table 7.

Table 7. Compaction characteristics of B C soil treated with the varying percentages of MT and lime

Mixtures	MDD (kN/m³)	OMC (%)
BCS+10%MT+4%LIME	16.5	24
BCS+20%MT+4%LIME	16.5	26
BCS+30%MT+4%LIME	16.8	25.8
BCS+40%MT+4%LIME	17.4	24.7
BCS+50%MT+4%LIME	17.8	24.4

4.6 Strength Behavior (UCS) of B C Soils

The UCS of B C Soil is 40.07 kN/m². Addition of 10-50 % of mine tailings to B C Soil the strength raises and the

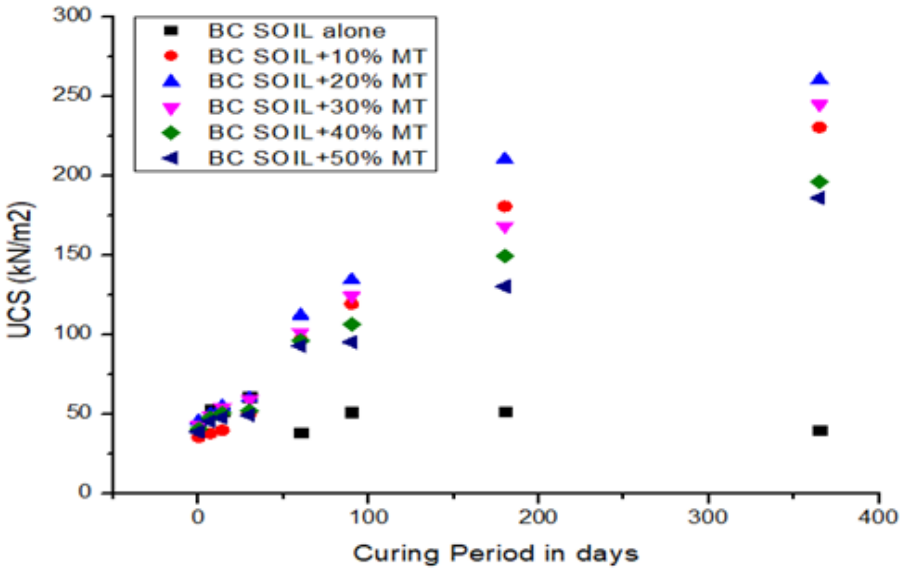


Figure 1. Variation of UCS of BCS and MT mixtures for different curing periods.

Table 8. UCS of BC Soil and MT mixtures for varying curing periods

Mixtures	UCS (kN/m²)							
	Curing in days							
	0	7	14	30	60	90	180	365
BCS alone	40.07	53.62	51.77	61.07	38.53	51.53	51.83	40.07
BCS + 10% MT	35.73	38.09	40.06	50.98	96.54	119.5	180.9	230.6
BCS + 20% MT	45.82	50.16	55.02	60.25	112.34	134.6	210.6	260.5
BCS + 30% MT	43.66	49.08	54.34	59.64	101.56	124.5	168.5	245
BCS + 40% MT	41.05	47.99	51.02	52.36	96.5	106.5	149.5	196.5
BCS + 50% MT	39.02	45.67	47.92	49.6	93.2	95.6	130.5	186.2

result is 260.5kN/m² on addition of 20% mine tailings for 365 day of curing. Strength achieving is because of the clay to silt interaction which lead to reduction in repulsion offered by densification and hence MDD increases which resulted in the increase of strength. Further adding of mine tailings beyond 20% the strength reduces because of the percentage of silt-to-silt interaction is more than clay to silt interaction, thus resistance offered by soil-mine tailings against compacting energy decreases this leads to reduction in MDD which causes decrease in the strength.

The strength of B C Soil increases upto 20% mine tailings, hence 20% addition of mine tailings for the B C Soil is considered as optimum percentage. The variation is as shown in Table 8.

4.6.1 Optimization of Lime for Bcs-Mt Mixtures

The UCS of B C Soil is found to be 40.07 kN/m². Adding of 4% of lime content was considered as the optimum percentage. This is attributed to the strength gain in lime treated MT with B C Soil involves two reactions such as

Table 9. UCS of BCS and MT treated with varying percentages of lime for varying curing period

Mixtures	UCS (kN/m²)							
	Curing in number of days							
	0	7	14	30	60	90	180	365
BCS alone	40.07	53.62	51.77	61.07	38.53	51.53	51.83	40.07
BCS+10%MT+LIME	50.3	70.52	112.5	196.25	265.54	375.8	452	532.2
BCS+20%MT+LIME	60.5	79.06	165.2	240.63	345.5	395.6	475.3	582.2
BCS+30%MT+LIME	56.5	61.2	135.6	210.63	286.5	315.6	425.5	495.6
BCS+40%MT+LIME	51.5	59.56	139.2	196.5	265.4	285.6	415.2	476.23
BCS+50%MT+LIME	49.05	55.64	105.2	175.6	255.5	269.3	355.3	415.2

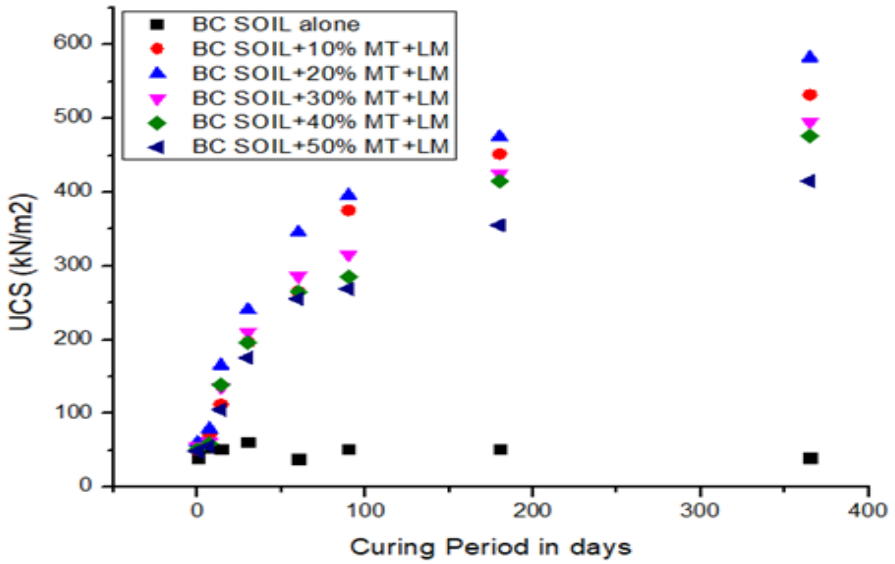


Figure 2. Variation of UCS of BCS, MT and lime mixtures for varying curing periods.

hydration and pozzolanic reaction[26]. Calcium hydroxide that is obtained from hydration of lime dissolves in the water. As a result, pH and calcium concentration of pore fluid also increases. The hydrous alumina in mine tailings reacts with calcium ion present in lime to form insoluble compound of Calcium Alumina Hydrate (CAH Secondary cement type product). This reaction is familiar as the pozzolanic reaction[27], which results to the raise in the strength. The improvement of strength of B C soil added with different percentage (10-50 %) of mine tailings with optimum lime is shown in Table 9.

5. Sem Analysis of B C Soil Treated with Mt and Lime

The experimental results of B C soil treated with 20% MT and lime combination achieves the highest strength when compared to other combinations added to the BCS. SEM analysis is conducted for a curing day of 7 days, 120 days and 365 days of the combinations. SEM images for 20, 50 and 100 microns were studied for different curing periods of 7 days, 120 days and 365 days curing periods. Adding of lime to MT is expected to enhance its cohesive property and hence increases its compressive strength.

The developing and maintenance of stiffness and high strength of the soil is gained by the elimination of the large pores by binding particles together by the maintenance of flocculent particle arrangement and by preventing the swelling and because of the development of pozzolanic materials. Lime and mine tailing is added to improve the formation and development of pozzolanic reaction in the samples and to study the effect of the additives on the strength of the treated specimen for curing periods up to 365 days.

Scanning electron monographs of 365-day curing samples show that at different stages of the pozzolanic action, the above section 3 hardened paste microstructure begins to form. This is because of the pozzolanic reaction in the early stage of the work, which leads to the occurrence of a thin layer of hydrated material on the surface. The inner part of the sheet is made of denser material, while the outer layer is made of fiber material. Erosion and wear may occur on the particle surface. It is assumed that in the early stages, the residues act as nucleation sites for the hydration of cement hydration compounds and for pozzolanic reactions. Scanning electron image taken 365 days after curing of the sample shows that its microstructure contains lime-treated residues forming Calcium Silicate Hydrate (CSH) or Calcium Aluminum Hydroxide (CASH) coagulation. There is a lot of reaction as shown in Figure 8. During the longer curing period of

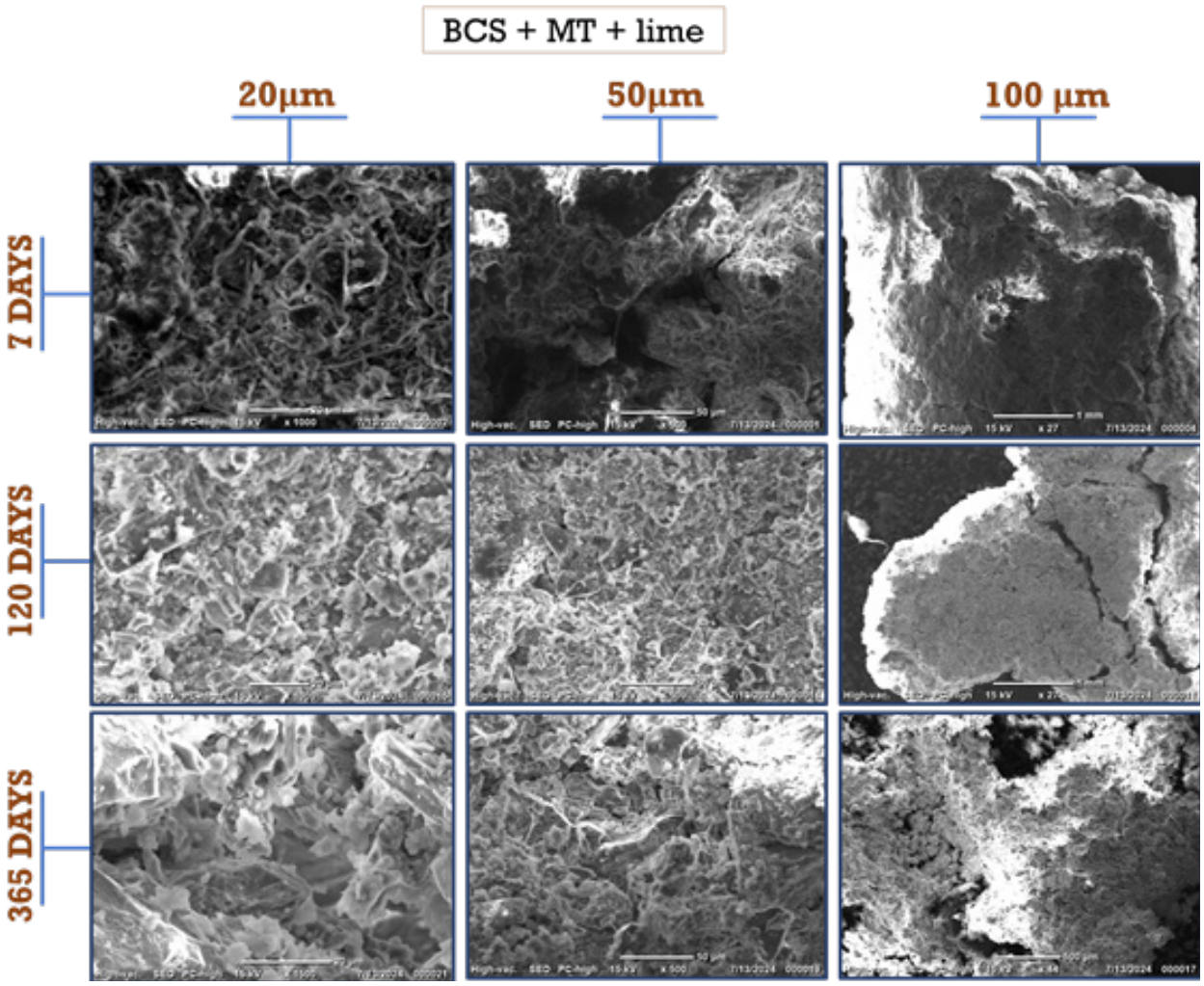


Figure 3. Sem image of black cotton treated with mt and lime for different resolutions.

365 days, SEM showed that the gel-like material covered the entire mixture and formed common areas. The boundaries are blurred and the gel is dense as the adhesive material is evenly distributed to form a dense structure. It helps to increase speed and power by providing more contact and tracking in hard debris.

A series of SEM micrographs showing the microstructural changes of a material over different curing periods: 7 days, 120 days, and 365 days. The images are taken at three different magnifications: 20 µm, 50 µm, and 100 µm. The SEM micrographs illustrate the material's internal structure, shedding light on the physical and also chemical transformations that occur during the curing process.

5.1 Experimental Conditions

High-vacuum: The image was taken under high-vacuum conditions, ensuring that the sample's surface is not affected by atmospheric gases.

SED PC-high: The imaging mode used is likely a Secondary Electron Detector (SED) operating in high-resolution mode. This provides a detailed information about the surface topography.

The Scanning Electron Microscopic (SEM) images show the microstructure of a BC Soil (BCS) sample treated with Lime and Mine Tile at different curing periods: 7 days, 120 days, and 365 days. By analyzing the differences between these images, we can gain information of the long-term interactions between the

soil components and the effect of curing on the soil structure.

5.2 Microstructural Analysis

At 7 Days

- The image gives relatively a rough surface with some small aggregates. The Lime and Mine tile particle may not have fully reacted with the soil yet, resulting in a less homogeneous microstructure.
- The micrograph at this scale reveals a highly porous and fibrous structure, with a loose network of particles. The texture appears rough, indicating the material is in the early state of curing, with significant void spaces present.
- At this magnification, the material displays a slightly more consolidated structure, though it still contains numerous voids and gaps between the particles. The fibers and particles are beginning to aggregate, but the material remains relatively loose.
- The micrograph shows a large, fractured particle with a rough surface. The presence of cracks and unfilled voids indicates that the material is still in the early state of strength development, with limited cohesion between the particles.

At 120 Days

- The surface appears smoother and more compact than the 7-day sample. This shows over time, the Lime and Mine tailing have reacted with the soil, leads to the formation of new mineral phases and the development of a more cohesive structure.
- The microstructure has become denser, with a reduction in visible voids. The material appears more homogeneous, suggesting the ongoing process of particle bonding and consolidation. The roughness of the texture has decreased compared to the 7-day sample[25].
- The material shows further consolidation, with fewer gaps and more uniform scattering of particles. The fibers are more compactly packed, indicating the raise in the material's density and mechanical strength.
- The micrograph reveals a more compacted structure with fewer cracks. The surface of particles appears smoother, and the overall material seems to be undergoing significant hardening, with improved cohesion and reduced porosity.

At 365 Days

- The surface is even smoother and more compact than the 120-day sample. This indicates that the curing process has continued to enhance the soil's structure, possibly through further mineral formation and the development of stronger bonds between the soil particles.
- The microstructure at 365 days is highly compact and dense, with minimal visible voids. The particles are well-bonded, and the fibrous texture is less prominent, indicating the material has reached a mature state with significant strength.
- The SEM image shows a well-developed microstructure with a continuous matrix. The material appears fully consolidated, with a smooth texture and tightly packed particles, reflecting the extensive curing and stabilization that has occurred.
- the material exhibits a robust structure with minimal surface defects. The heavy particle seen in the graph is intact with small visible cracks which indicates that the material has undergone complete hardening and is now structurally stable.

The SEM micrographs clearly show the progression of the material microstructure over time. In the first 7 days, the material is porous and loosely packed, indicating the early stages of the healing process. As the time increases to 120 days, it is shown that the product shows good improvement in density and particle structure, and that physical modification contributes to energy consumption. On the 365th day, the same material reaches the junction with minimum voids and cracks, indicating that the repair process is complete. It undergoes successive hydration and pozzolanic reaction to form a stable phase, thus increasing the mechanical strength of the product. This image clearly shows the transition from brittle to porous to thick and strong materials, emphasizing the importance of the curing time to achieve good quality.

5.3 Scientific Explanation

The observed changes in the microstructure of the BCS sample over time can be attributed to several factors:

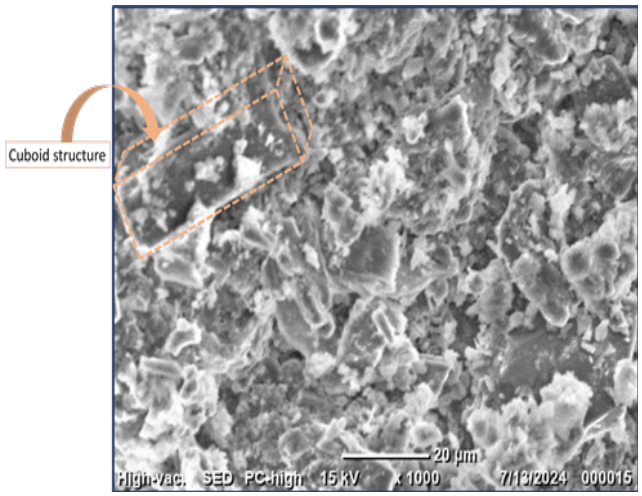


Figure 4. SEM image showing cuboid structure.

- Lime-Soil Reactions: Lime CaO or Ca $(OH)_2$) reacts with the clay minerals in the soil, forming new mineral phases such as Calcium Silicate Hydrates (CSH). These CSH phases can improve the soil's structure by filling the voids between the soil particles and providing a binding matrix.
- Mine Tile-Soil Interactions: Mine tile, which is often rich in minerals and organic matter, can also interact with the soil components. The organic matter may decompose over time, releasing nutrients that can promote microbial activity and influence the soil's properties.
- Curing Process: Curing involves the gradual hydration and hardening of the soil-cement mixture. Over time, the water content in the soil decreases, leading to the formation of stronger bonds between the soil particles and the newly formed mineral phases.

The SEM images demonstrate the significant impact of curing time on the microstructure of the B C Soil treated with Lime and Mine Tile. As the curing period increases, the soil's structure becomes more compact and cohesive, likely due to the formation of new mineral phases and the strengthening of bonds between the soil particles, the cuboid structure in the SEM image indicates the formation of bond. These changes can have positive effects on the soil's physical and mechanical properties, such as its strength, permeability, and resistance to erosion.

6. EDX of Expansive BCS Treated with MT and Lime

Energy Dispersive X-ray Spectroscopy (EDS or EDX) is a powerful analytical technique used for the elemental analysis and chemical characterization of materials. The provided spectrum allows for the identification of elements present in the sample by detecting the characteristic X-rays emitted from the sample when it is bombarded with a focused electron beam. he EDS

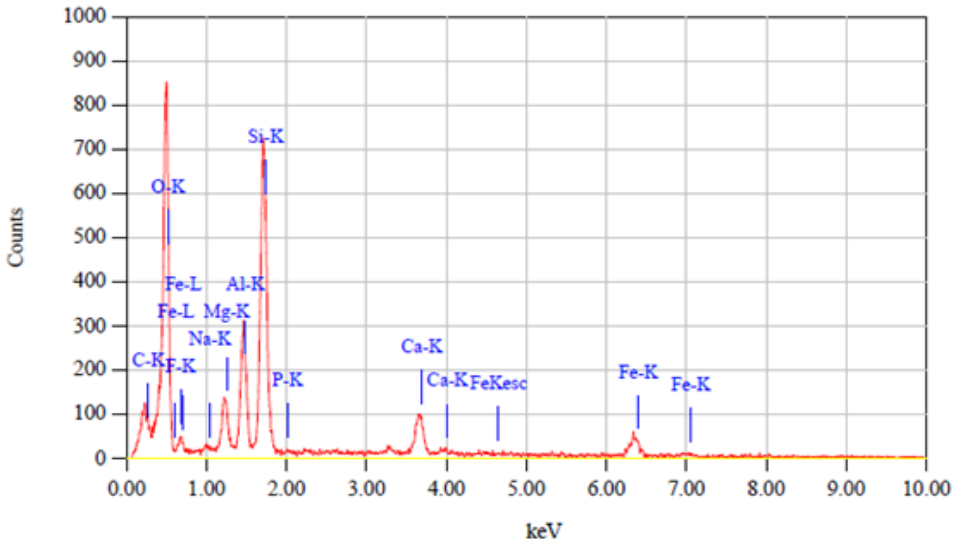


Figure 5. EDS micrograph of BCS, MT and lime for 7days curing period.

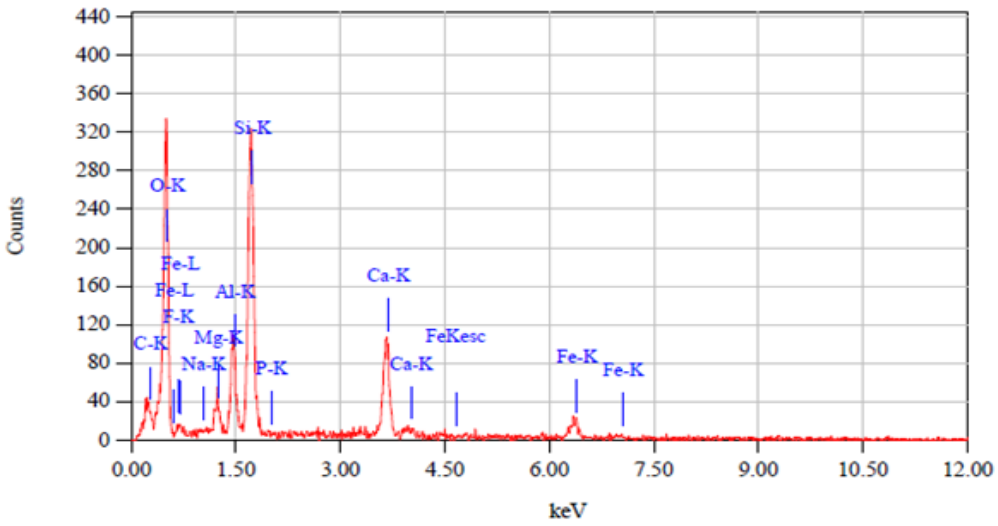


Figure 6. EDS micrograph of BCS, MT and lime for 120 days curing period.

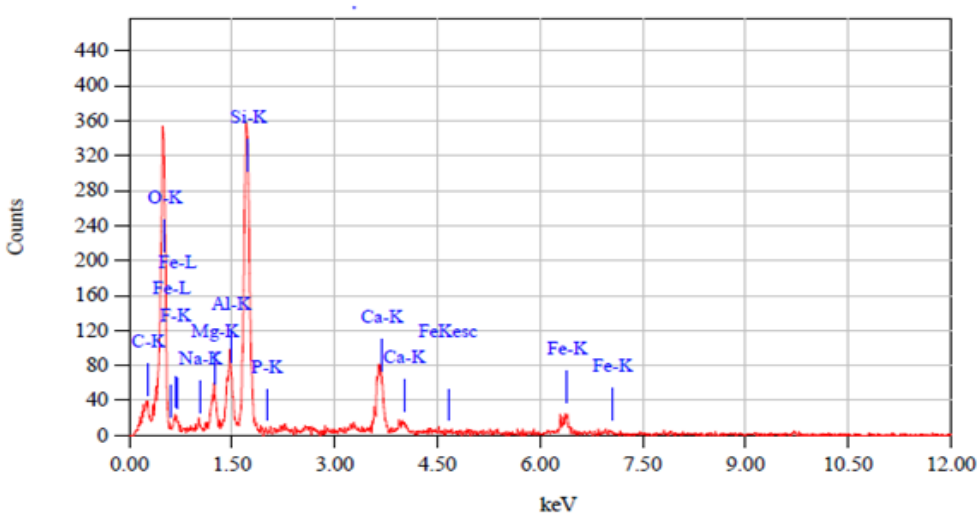


Figure 7. EDS micrograph of BCS, MT and lime for 365 days curing period.

spectrum presented spans an energy range from 0 keV to 12 keV, with the X-axis representing the energy of the detected X-rays in kiloelectronvolts (keV) and the Y-axis representing the count of X-rays detected at each energy level. The spectrum reveals the presence of various elements in the sample, with peaks corresponding to characteristic X-ray energies for each element. EDS is a technique used to identify the elemental composition of materials by detecting X-rays emitted from the sample when it is bombarded with an electron beam. The EDS micrographs Figure 9. of mine tailings with lime for immediate 7 days of cured samples show distinct peaks of (Al, Si, and Ca) were seen at many peaks which proves that hydration of lime has taken place and stabilizing compounds of cement hydration compounds are formed.

The spectrum reveals that the sample is predominantly composed of silicon (Si), oxygen (O), and iron (Fe), as indicated by the prominent peaks at approximately 1.74 keV (Si-K), 0.52 keV (O-K), and 6.4 keV (Fe-K). The presence of magnesium

(Mg), aluminum (Al), and calcium (Ca) suggests that the sample may contain minerals such as silicates, aluminosilicates, or other oxides commonly found in geological samples or certain types of alloys. The presence of carbon (C-K) at approximately 0.28 keV may indicate organic contamination or the presence of carbon-based materials within the sample. The small peaks corresponding to phosphorus (P-K) suggest a minor presence of this element.

The presence of silicon, oxygen, and iron as the most prominent peaks suggests that the sample is rich in silicate minerals, possibly containing iron-rich phases such as magnetite or hematite. The presence of aluminum, magnesium, and calcium supports this interpretation, pointing towards a complex mineralogy typical of igneous or metamorphic rocks. The relatively lower counts for carbon may indicate contamination or the presence of organic materials, while the detection of phosphorus might suggest a minor component like apatite or another phosphate mineral. The identified elements, along with the escape peak observed for iron, suggest a complex sample composition where silicate and oxide phases dominate. The accuracy of this interpretation would benefit from additional analysis, such as phase identification through X-Ray Diffraction (XRD) or further EDS mapping to explore the spatial distribution of these elements within the sample.

The spectrum reveals that the sample is composed of a mix of elements, with silicon, oxygen, and iron being the most prominent. The presence of these elements suggests that the sample could be a silicate mineral or a material with significant oxide and silicate content such as a geological sample or an industrial material.

The massive peaks of silicon and oxygen are indicative of a silicate cloth that is a not usual constituent of many rocks and ceramics. The incidence of multiple iron peaks suggests that the pattern consists of a sizable quantity of iron which can be inside the shape of iron oxide minerals or as part of the matrix in a composite cloth. Aluminium and Magnesium are often coexisted with silicon in minerals such as feldspar or in certain alloys. The calcium peaks might also show the presence of calcite and phosphorus will be related to apatite or other phosphate minerals. The carbon top may want to suggest natural infection or the occurrence of carbon-based totally materials in the sample. If carbon coating is used throughout the sample instruction for SEM analysis this may also make a contribution to the peak. The presence of iron suggest that the material may have magnetic residence or used in packages requiring iron-bearing compounds. Findings of aluminium, magnesium, and calcium further indicates that the sample has a complicated mineralogical composition which doubtlessly making it appropriate for creation and production or even technological applications where unique elemental properties are required.

7.0 Conclusion

From the research work carried out on BC soil and MT the following experimental results were concluded.

The addition of Mine Tailings (MT) to Black Cotton (BC) soil led to a noticeable improvement in its geotechnical properties. The Specific Gravity (SG) of BC soil increased from 2.53 to 2.67, attributed to the replacement of lower-density BC soil particles with the higher-density MT particles.

The Liquid Limit (LL) of BC soil decreased significantly from 58.4% to 43.21% with the inclusion of MT, and further reduced to 37.11% when lime was added. This reduction is due to enhanced flocculation and water entrapment within the voids of the flocculated structure, which was observed across varying curing periods.

The Plastic Limit (PL) initially decreased from 30.1% to 19.23% with MT addition but exhibited a slight increase with extended curing. A similar trend was observed with lime-treated MT-BC soil mixtures, attributed to a reduction in the diffuse double-layer thickness and subsequent particle flocculation during curing.

The Shrinkage Limit (SL) of BC soil increased from 8.4% to 18.4% upon the addition of MT, both immediately and with prolonged curing. This increase is linked to cation exchange-induced flocculation and particle agglomeration over time.

The Maximum Dry Density (MDD) of BC soil increased from 15.8 kN/m^3 to 16.3 kN/m^3, while the Optimum Moisture Content (OMC) decreased from 25.9% to 24% with MT addition. This behavior can be attributed to reduced repulsive forces between particles,

allowing them to compact more effectively, resulting in a lower void ratio and higher density.

The Unconfined Compressive Strength (UCS) of BC soil showed a remarkable improvement, increasing from 40.07 kN/m² to 260.5 kN/m² with curing time. The highest strength was observed at a combination of 4% lime and 20% MT after extended curing, indicating the optimal stabilization mix. These results demonstrate the effectiveness of MT and lime in enhancing the engineering properties of BC soil for construction purposes

Scanning Electron Microscopy (SEM) images captured after a 365-day curing period revealed significant microstructural changes in the stabilized soil. The hydration of Mine Tailings (MT) and lime particles resulted in the formation of Calcium-Silicate-Hydrate (CSH) and Calcium-Aluminium-Silicate-Hydroxide (CASH) gel-like compounds. These hydration products effectively filled the voids between soil particles, creating a denser and more cohesive structure. The formation of these gels is indicative of pozzolanic reactions, which contributed to the substantial improvement in the strength and overall stability of the treated Black Cotton soil.

8.0 References

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