Stabilization of expansive soil with terrasil and coir fiber as a subgrade for pavement

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Abstract: This research is intended to enhance the strength and permeability properties of black cotton soil or expansive soil of high plastic clay (CH) by combining soil with coir fibre and Terrasil additives. The distributions of the additive's coir fibre and Terrasil used in the analysis are expressed as a percentage of the soil's dry weight. The Terrasil and coir fibre proportions used in this study are 0.5% Terrasil and 0.5%,1.0%,1.5%, and 2.0% coir fibre, respectively. According to the analysis or test results, clay subgrade soil stabilized with 0.5% Terrasil and 1.5% coir fibre exhibits specific values for strength and CBR value improvement. The UCS confidence interval for the combined application of soil+0.5%Terrasil+1.5%coir fibre increases from 26.566 kpa to 27.209 kpa in the untreated soil. The CBR computed value for the treated soil is 90% usually higher than the untreated soil, lowering the layers demanded for the subgrade.Permeability values of 1.5% and 2.0% for coir fibre and 0.5% for Terrasil outperformed that of untreated soil. After the additives are incorporated into the soil, the mineralogy of the soil and the Bonding mechanism phenomena are inspected (or) investigated using XRD, SEM, and FTIR.

Keywords: High Plastic Clay, Terrasil, Coir Fiber, California Bearing Ratio, Unconfined Compressive Strength, Agglomeration.

1 INTRODUCTION

Soil is an important aspect of this ecosystem. There are multiple kinds of soils in the environment that we use in our daily project constructions. Currently, most construction zones have an abundance of black cotton soil. Because of its tendency to deform and swell due to variations in moisture content, black cotton soil (BCS) is also known as problematic soil [20]. There It is fertile soil with a wide range of colours and properties. Expansive soils become plastic and deform in wet conditions. As a result, unfavorable and harmful outcomes emerge. Take preventive measures such as stabilization and ground improvement techniques before using the soil for construction. The most common mode of transportation is the motorway.

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Because of the increased traffic volume on the roads, a massive road structure is required. The main issue was that the majority of the pavements were constructed on expansive soil. Because of the large change in soil volume caused by moisture content, the construction will fail [3]. Stabilization can strengthen the soil, and physical properties like shear strength and bearing efficiency can be improved by using admixtures like fly ash, lime, and bentonite clay, as well as other nanoparticles, or through the use of geosynthetics, among so many other things [2]. Soil stabilization involves an increase in the index properties of the soil to mean the measuring project performance of highway construction and to enhance soil mechanical performance [1].Previously, soil stabilization was used to manage pavement erosion [23]. There are several goals for soil stabilization, yet the most prevalent is to augment the strength of the soil so that the soil can counteract the various loads. It also diminishes permeability and reduces porosity in the soil, attempting to make it far more resilient [18]. The subgrade must be assembled as a rigid body at a low cost. To stabilize pavement soil sub-base courses, bio enzymes, and chemical, organic, and liquid compounds were deployed [22].To stabilize the subgrade soil throughout highway construction, additives often including lime, cement, fly ash, and nano chemicals such as silicon, Zycobond, and Terrasil were incorporated. They substantially increase the CBR value as well as aid in the construction of pavements at a low cost [9]. This analysis prioritizes subgrade stabilization using coir fibre and Terrasil, which serves as the material to build subgrade pavement.

1.1 Materials

1.1.1 *Soil*

A soil sample was acquired from Yanamalakuduru, Vijayawada, Andhra Pradesh, for this research work. The soil had been gathered at a depth of 2m to remove any unnecessary gravel, debris, or waste without ever being transported to the laboratory for various tests such as grain size distribution, atterberg limits, permeability, proctor tests, CBR test, and UCS test. Finally, the findings revealed that the soil observed from the sampling location seemed to be High plastic clay (CH).

1.1.2 *Coir fiber*

Coir fibre is an organic fibrous process of removal from the husk of the coconut with waterproof and tensile attributes. Coir fibre is a kind of strong structural fibre. There are two kinds: brown fibre, which is strong and elastic, and the finest for elongating without splitting. It is merely used in highway construction, alongside a different white coir fibre, which is immature and easily breaks. Brown coir fibre is used in this study to conduct the analysis [14].

1.1.3 *Terrasil (Ter)*

Terrasil is a biomaterial in the form of a yellowish water solvent that is used to reduce the water that percolates into soils. The Terrasil bond is a silicon oxide bond. It has a uniqueness that prevents the soil from being absorbed by water while allowing water vapor to escape and controlling the increasingly broad soil's cellular structure. There will be no negative consequences after the soil has been treated.

Table 1: Properties Of Natural Soil.

Properties	**Value**
Gravel	-
Sand	5.4%
Clay and silt	93.6%
Specific gravity	2.59
Liquid limit	56%
Plastic limit	29%
Shrinkage limit	17%
Plasticity index	27%
Type of soil	**CH**
Optimum moisture content	12%
Maximum dry density	1.64 g/cc
California bearing ratio a. Soaked cbr b. Unsoaked cbr	 3.6% 4.8%
Unconfined compressive test	12.91 kpa
Permeability	1.56* 10^{-7} cm/sec

Table 2: Properties Of Coir Fiber.

Properties	**Values**
Length	6-8mm
Density	1.38 g/cc
Tenacity	10 g/tex
Diameter	0.1-1.5 mm
Breaking elongation	30%
Swelling	10.5

Table 3: Properties of Terrasil.

Properties	**Values**
Hydroxyalkyl-alkoxy-alkyl silyl	65-70 %
Benzyl alcohol	25-27%
Ethylene glycol	3-5%

2 METHODOLOGY

Several laboratory tests were conducted to determine the properties of both natural soil and soil mixed with various proportions of coir fiber(0.25%,0.5%,0.75%, and 1%) and Terrasil (0.5%,1%,1.5%,2%). Various tests have been carried out to investigate the properties of stabilized subgrade soil are Atterberg's limit test, Standard Proctor test, Unconfined compressive strength test, and CBR test, permeability test.At least four specimens were examined for each test in order to obtain an accurate value.The accompanying IS: Codes have alluded to the performance of the test.

2.1 Atterberg Limit

The Atterberg limit was utilized for correlations as well as to assess the index qualities of the untreated soil and categorize the type of soil. According to IS: 2720 (Part 5) - 1985, the Atterberg limit [5] tests were conducted.

2.2 Standard Proctor Test

To ascertain the relationship between soil moisture content (or) water content and dry density for specific compaction energy, the proctor test is used. The test is conducted for both treated and untreated soil samples it is carried out in accordance with IS: 2720 (Part 7) -1980 [7] in a laboratory.

2.3 California Bearing Ratio(CBR)

To determine the subgrade's strength, the soil underwent the CBR test. Both the soaked and unsoaked soil mix proportion specimens were tested, and the laboratory test was carried out in conformance with IS: 2720 (Part 16) – 1987 witha load of 1.25mm per minute [16].

2.4 Unconfined Compressive Strength(UCS)

The most common tactic for assessing the soil's shear strength for both mixed soil proportions and untreated soil was the UCC test. According to IS: 2720 (Part 10) - 1991, the test was performed on a specimen of the requisite size to evaluate its strength at zero confining pressures [8] with an axial strain of 0.5 to 2 percent per minute.

2.5 Permeability Test

The permeability of the soil is gauged using a permeability apparatus of the falling head type. IS: 2720 (Part 17)-1986 is followed when the soil is well compacted in the mould and water is passed through the soil to determine the coefficient of permeability [17].

2.6 Microstructural Tests

In this research, the progress of microstructure in the material was examined using XRD, SEM, and FTIR. The SEM phase included in a specimen was determined by using XRD.With the help of Bruker D2 phrases from 5 to 80 of $2\theta^{\circ}$, the XRD will inspect the sample.An expert high-scoring piece of software was used to evaluate the diffraction patterns.The numerous kinds of chemical bonds that are present in the sample can be recognized at the molecular level using FTIR. The sample was pressed into the pellets with the help of hydraulic pressure and inserted into the spectrometer the spectra were recorded in the range of wavelengths from 550 cm^{-1} to 5000 cm^{-1}.

3 RESULTS AND DISCUSSIONS

3.1 Standard Proctor Test

The compaction characteristics of the soil are critical parameters in determining the strength and durability of pavements built on clayey subgrades [7]. Any subgrade soil prepared at the optimum moisture content (OMC) can maintain sufficient stability over time. The compaction specifications are vital for achieving the required pavement sustainability [4]. For the test analysis, the different combinations of 0.5 %Terrasil as a constant and 0.5%,1.0%,1.5%, and 2.0% of coir fiber are used.

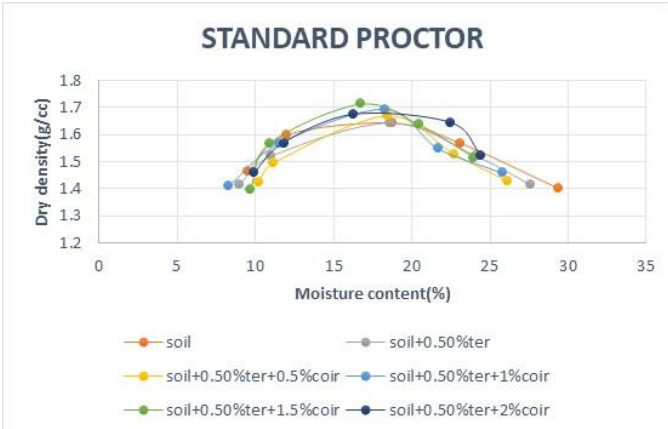

Fig. 1: Compaction curves for treated and untreated soil

Table 4: Effect of coir fiber and Terrasil on MDD and OMC.

SOIL	MDD (g/cc)	OMC (%)
UNTREATED SOIL	1.486	12
SOIL+0.5% TER	1.645	18.61
SOIL+0.50%TER+0.5% COIR	1.67	18.81
SOIL+0.50%TER+1%COIR	1.692	18.27
SOIL+0.50%TER+1.5% COIR	1.72	16.9
SOIL+0.50%TER+2%COIR	1.682	18

The values depict the variation of maximum Optimum moisture content and dry density with the percentage of Terrasil and coir fiber as shown in Figure 1 and tabulated in Table 4.It can be seen that an increase in the coir fiber percentage of 0.5% to 1.5%, increases the MDD value from 1.48 g/cc to 1.72g/cc, and we can see that further increase in the coir fiber from 1.5% to 2% the MDD value is decreased from 1.72g/cc to

1.682g/cc because the replacement of soil with two lightweight materialswill change the densities of the soil proportion and also reduced the water proportion [12].so the OMC of the soil is changed from 18.75% to 16.9%.

3.2 California Bearing Ratio Test

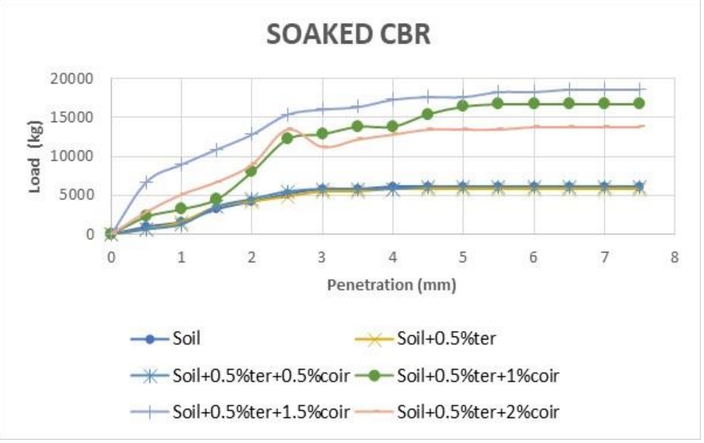

Fig. 2: Soaked California bearing ration Load vs Penetration

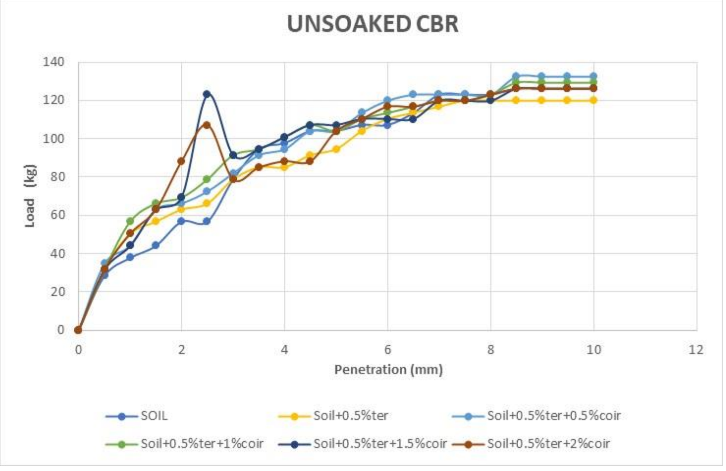

Fig. 3: Unsoaked California bearing ration Load vs Penetration

The subgrade's California bearing ratio (CBR) is an important strength characteristic for predicting the thickness of the pavement's subgrade [16]. According to IS: 2720 (Part 16) – 1987 the CBR values for clay subgrades are low [12]. Different admixtures must be used to enhance the CBR of the clay subgrade. The California bearing ratio test was engaged for both soaked and unsoaked states for standard compaction results with the proportions of constant 0.5 %Terrasil with 0.5%,1.0%,1.5%, and 2% of coir fiber content.

Table 5: Relationship between load and penetration for various coir fiber andterrasil content ratios

SOIL	SOAKED CBR (%)	UNSOAKED CBR (%)
UNTREATED SOIL	3.67	4.13
SOIL+0.50%TER	3.44	4.82
SOIL+0.50%TER+0.5%COIR	3.90	5.28
SOIL+0.50%TER+1%COIR	8.73	5.74
SOIL+0.50%TER+1.5%COIR	11.03	8.69
SOIL+0.50%TER+2%COIR	9.65	7.81

The CBR values for the soaked and unsoaked values are shown in the tables. The CBR values are enhanced with the percentage of the coir fiber content up to 1.5% and decrease after further increasing the percentage ratio. The CBR value for the soaked value increases from 3.67% to 11.06%,it is 3.3 times higher than untreated soil, and also for unsoaked conditions, the CBR value increased by 2.1 times than the untreated soil was 8.9% to 4.1%. The increase in the CBR value with increasing dosage of coir fiber and Terrasil is because the shear resistance was increased in soil because of the agglomeration which leads to resisting the loading which is caused by the penetration.

3.3 Unconfined Compressive Test

As per IS:2720(part-10), the UCS test was performed on both unreinforced & reinforced soil specimen samples at a constant strain of 0.125mm/minute [8].The specimens were evaluated for coir fiber content ranging from 0.5% to 2.0% at 0.5% increments, whereas keeping the Terrasil constant at 0.5%.The results of the compressive strength parameters of the various combinations are been tested under a compressive force. The results for various mix combinations didn’t show any appreciable growth in the strength, withanan increase in the coir fiber content the strength value is gradually increased [4] as shown in Fig 2, and values are tabulated in table 6.

From the values, we can observe that the UCS for reinforced soil is 2.3 times higher than the unreinforced soil occurs at the combination of soil+0.5% Terrasil+1.5% coir fiber. The UCS value was enhanced from 12.915 kpa to 28.92 kpa and further increase in coir fiber content up to 2% the UCS got decreased from 28.92 kpa to 26.52 kpa the reason behind it was that Terrasil acts as a water-resistive agent it fills the pores of the soil and the coir fiber which replacing the soil is tensile in nature so the soil is adapting a spring behavior [13].With an increase in fiber content, the effectiveness of the soil matrix accessible to grab the fibers is inadequate to establish a strong bond between the materials of fiber, Terrasil, and soil [15].

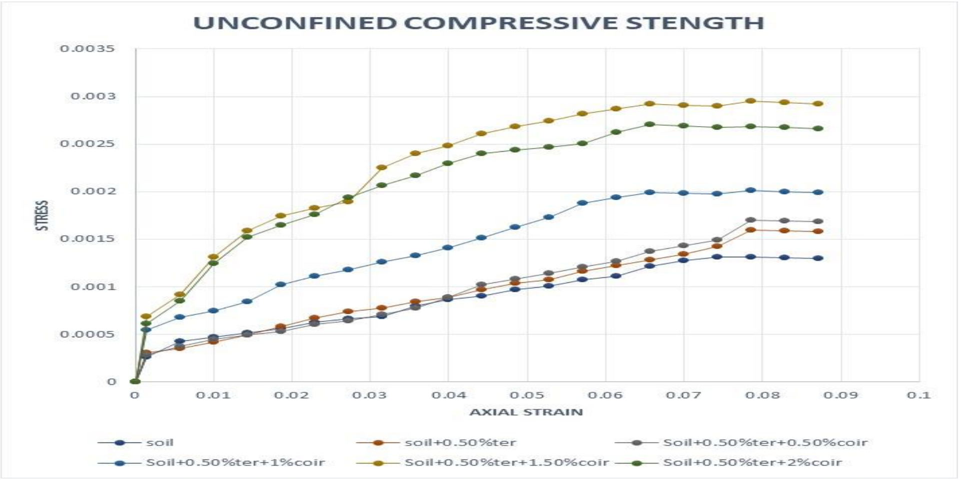

Fig.4. Stress-strain relationship of untreated soil and treated soil

Table 6: Coir fiber and terrasil effect on shear strength of soil.

SOIL	UCC (Kpa)
UNTREATED SOIL	12.9154
SOIL+0.5% TER	15.6399
SOIL+0.50%TER+0.5% COIR	16.7113
SOIL+0.50%TER+1%COIR	21.5843
SOIL+0.50%TER+1.5% COIR	28.92315
SOIL+0.50%TER+2%COIR	26.5026

3.4.Permeability Test

The values observed in the table show that an increase in the Terrasil and coir fibercontent reduces the permeability nature from $1.56*10^{-7}$ to $0.79*10^{-7}$.

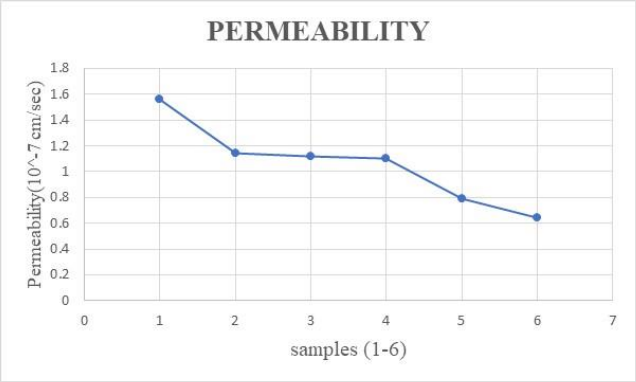

Fig.5. Permeability of untreated and treated soil

The optimal values for the permeability were observed for both percentages of soil with 0.50%ter + 1.5% coir & 0.50%ter + 1.5% coir [10]. The permeability value has been depleted because of the increment of Terrasil and coir fiber content which reduces the gaps and changes the soil matrix. So, while increasing of additive content the permeability values got decreased [17].By virtue of the agglomeration phenomenon, the voids in the soil are clogged with both coir fibre and Terrasil, creating a dense matrix that limits soil permeability [16].

Table 7: Terrasil and coir fiber's impact on Permeability

PERMEABILITY	SAMPLE
1.56	1
1.14	2
1.12	3
1.1	4
0.79	5
0.64	6

3.5. Fourier Transform Infrared Spectroscopy

The whole micro-level analysis is done for untreated soil and for the treated soils percentage of 0.50% Ter because in this study the optimum and considerable values were acquired for the above-mentioned chemical additive percentage in soil.Utilizing Fourier transform infrared spectroscopy to analyze the absorption bands at distinctive wavelengths of bonds, it is possible to identify the functional groups of soil minerals. Figure 4 depicts the FTIR spectrum of black cotton soil post-Terrasil treatment.The values represented in the graph show the relevant positions and band allocations [21].In addition to the typical band assignments for montmorillonite, diagnostic quartz, and silica bands that are present in the sample can be seen at 697, 792, and 1005 cm^{-1}.The XRD analysis supports the existence of quartz and silica. The -OH stretching and inner hydroxyl group hydration were implicated for the 3697 cm^{-1} bands. Si-O and in-plane Si-O stretching is shown by the bands at 697 and 1005 cm^{-1}, respectively.

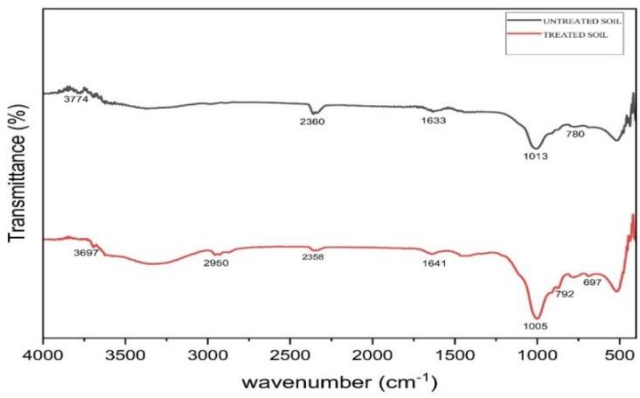

Fig.6: FTIR spectra graphs for untreated and treated soil

Treated black cotton soil's FTIR spectrum exhibits a band at 3697 cm^{-1} in -OH stretching, which indicates hydration from hydroxyl bonds with octahedral cations. Bands at 2358 cm^{-1} and 2950 cm^{-1} that reflect the change in Si concentration following the addition of the additive may be visible when the soil is treated with Terrasil, indicating that the peak patterns were influenced.Ion exchange will lead the clay particles to change and the diffused double gradually start to attract one another. Consequently, the layer-to-layer, layer attraction force will increase. The cation exchange system causes flocculation to develop.The adverse change has been observed in Si-O-Si when additives are mixed with soil.

3.6 X-RAY DIFFRACTION TEST

Both the natural soil and the soil treated with Terrasil and coir fiberunderwent an X-ray diffraction examination, and the x-ray diffractogram is shown in Fig 7a & 7b.A comparison of the XRD patterns of treated soil ratio of soil:0.5%ter:1.5%coir shows the effect on the development of the UCS and untreated soil.After examining the two diffractograms, we may imply that neither the XRD patterns of the untreated soils nor those of the treated soils have changed.

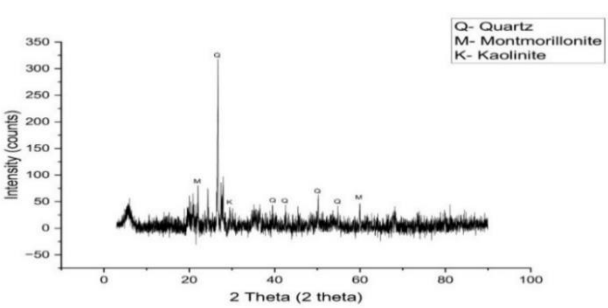

Fig.7a: XRD diffractograms for untreated soil

The apex widens as crystallite size decreases. The inverse relationship between crystallite size and peak width is seen. The x'pert high score plus the software's analytical data demonstrates the decrease in d-spacing. This causes a reduction in the free swell and greater bonding between clay minerals.The soil is impenetrable and has less swelling and shrinkage properties because of the silica bond, which also makes the soil impenetrable [24]. Since Terrasil is a nanoparticle and agglomeration occurs in soil, it is impossible to distinguish between the soil particle and Terrasil.

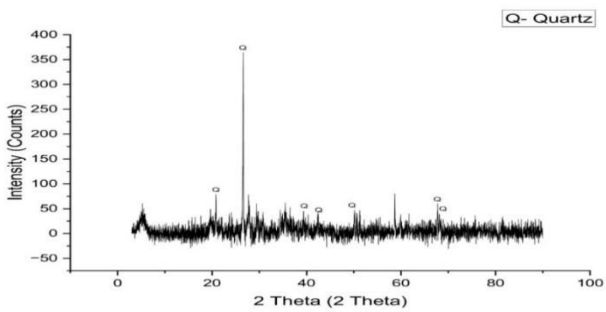

Fig.7b:XRD diffractograms for Treated soil

3.7 Scanning Electron Microscopy Test

The SEM is employed in the research to analyze the fundamental shift in the mineralogy of soil. The Scanning electron microscopy test (SEM) images of untreated clay soil are been shown in Fig 8 a. According to the image, untreated soil dispersed clay matrix with zero aggregation, implying that the soil is inevitably expansive and has high porosity gaps so the water will pass through it and makes the soil expansive [19].Fig 8 a & 8 b show SEM images of untreated and treated soil of 0.5% ter and 1.5% coir fiber with different magnifications of 10µm, 20µm, and 50µm for the image leading us to conclude that the treated soil particles are significantly more sealed than untreated soil particles.

Terrasil was added, which decreased the soil's porosity and revealed the treated soil's low porosity. Because of the chemical addition, the ions in the Terrasil stop water from entering.The fact that Terrasil is a nanoparticle will cause a little degree of flocculation to occur [14].The phenomenon of agglomeration involves the adhesion of two particles to each other or the solidification of a surface, which results in an increase in mass [11]. Fig 8 b shows the expansion of the mass when Terrasil is induced with the soil, the binding action between Terrasil and the soil has been developed immensely.The soil will be able to become incredibly resilient because of the silica bond [16]. The silicon and oxygen bond prevents water from penetrating the soil if it becomes saturated again under any circumstances because the bond transforms into a wall-like structure and functions as an anti-swelling agent [19]. The stability of the subgrade will be maintained exceptionally by inducing the coir fiberand the Terrasil.Because Terrasil and lime are related, the modification progress is kind of similar. When lime is employed, flocculation is predominantly accountable for altering the properties of clay [14].

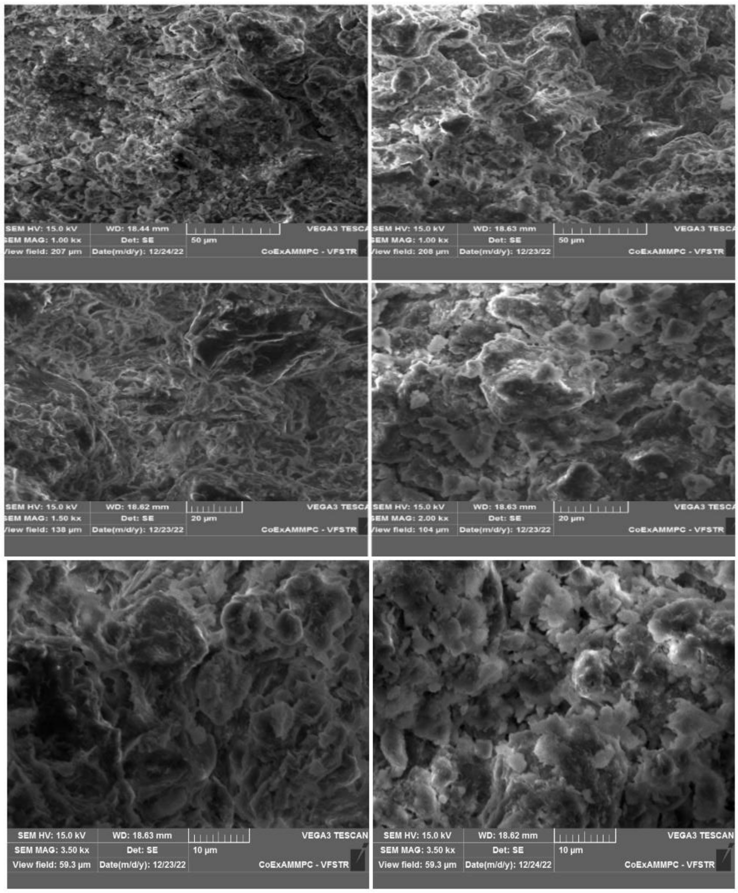

Fig.8:SEM images of untreated soil and treated soil

4 CONCLUSIONS

The amount of coir fiberand Terrasil needed for this study depends on the properties of the soil in order to get noticeable stabilization results. The conclusions reached as a result of the findings are outlined below

1. With the addition of Terrasil and coir fiber up to 0.5%+1.5%, it was shown that the OMC was reduced and the MDD increased; however, this tendency was found to be reversed with the addition of 2% coir to 0.5% Terrasil. This might have happened as a result of intergranular packing disruption and/or the replacement of soil by lightweight material, which lowers the MDD.

2. At last, it was determined that the treated soil's UCS increased up to 0.5% Terrasil + 1.5% coir fibercontent and decreased with 0.5% Terrasil + 2% coir fiber. Beyond the 0.5% Terrasil + 1.5% coir fiberaddition the reduction in UCS takes place, due to the rebound action in the soil, because the coir fiber is a tensile material, and by replacing more coir it adjusts to springing movement. In comparison to untreated soil, treated soil has a UCS value that is 2.3 times higher.

3. The CBR value is increased up to 3.3 times compared to the untreated soil with the addition of 1.5% coir fiber+ 0.5%terrasil for both the soaked and unsoaked conditions because the shear resistance in the soil increased due to the agglomeration phenomenon, which results in resisting the loading that is brought on by the penetration. This is why the CBR value improved when the dosage of coir fiber and Terrasil was at a certain level.

4. A thinner subgrade layer is needed for the pavement because the CBR value is enhanced with the addition of coir fiber and Terrasil.

5. The resultsshow that by involving the waterproof course Terrasil the water impenetrable into the soil so permeability has been reduced, because of the silica and oxygen bond the soil will become inseparable and voids were reduced.

6. The SEM image shows the difference between both the treated and untreated soilsamples where we can observe the major difference in the particle’s attraction due to the agglomeration phenomenon the pores have been reduced and changed their aggregation. We can conclude that the soil is more stable compared to the untreated soil.

7. Treated black cotton soil's FTIR spectrum exhibits a band at 3697 cm-1 in -OH stretching, which indicates hydration from hydroxyl bonds with octahedral cations. Bands at 2358 cm-1 and 2950 cm-1 that reflect the change in Si concentration following the addition of the additive may be visible when the soil is treated with Terrasil, indicating that the peak patterns were influenced.

8. The XRD graphs show that the minerals present in the soil with higher peaks in the spectrum represent a higher chemical concentration of element, particularly increases in the quartz amount in the sample containing Terrasil and coir fiber, which is responsible for the increase in strength attributed to the formation of layers and conglomeration in the soil particles.

9. The addition of the chemical additive Terrasil to the soil has had no negative effects (or) harmful effects. We can conclude that by adding Terrasil, the cohesion of the clay soil was significantly improved.

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