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(Review Article)

Effectiveness of Alccofine, Zycobond, and Terrasil as Clayey Soil Stabilizer: A review

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Abstract

Since the last two decades, India has seen a significant increase in infrastructure development, which has resulted in a rapid increase in pavement construction and structural foundation. Pavements and foundations for structures are generally laid on the soft ground during this process which is highly unfavorable for construction. Clayey soil is a difficult soil to work with because it is cohesive, highly unstable, and prone to volumetric shrinkage, has low shear strength, and is susceptible to moisture. The CBR of these subgrade soils is too low, causing the thickness of the pavement laminas to increase. It creates an undesirable requirement for usage of large number of natural resources. A cost-effective solution would be to convert locally available difficult soil into suitable construction material. So, first method is to ameliorate the properties of the available soil so as to meet the requirements, a process known as soil stabilization. The current study's scope is limited to investigating, the techniques of the stabilization process with respect to the CBR values as the CBR is the most important factor in determining the base material quality for the said purpose. This study compares results from different experiments conducted at different researchers. The effect of Zycobond and Terrasil in combination with Alccofine on clayey soil in various ranges was explored in this paper.

Keywords: Alccofine; CBR; Clayey Soil; Soil Stabilization; Terrasil; UCS

1. Introduction

Since the last two decades, India has seen a phenomenal surge in infrastructural development. Pavements and structural foundations are frequently laid on soft and unfavorable terrain as part of the procedure. Clayey soil is a very difficult soil to work with since it is cohesive in nature, highly susceptible to volumetric shrinkage, and has low shear strength and moisture susceptibility. In addition to these properties clayey soils retain too much water which makes it unfit for base material. As the California Bearing Ratio of subgrade soils is always low, the thickness of the base layers in pavements increases. It necessitates the use of enormous amounts of natural materials, resulting in the depletion of vital natural resources. Construction on such soils can sometimes result in problems such as low shear strength, significant differential and total settlement, liquefaction of soil and a lot of seepage. Researchers and engineers have been attempting to overcome problems caused by various forms of soft ground for decades. Due to the reasons mentioned above there is a need to improve their durability and strength. When low-quality soil is found on a building site, the structure may be constructed to manage it, or the poor soil can be substituted with acceptable material acquired from a nearby region. However, using soil directly from a nearby area does not usually fit to standards required for construction. As a result, it becomes necessary to adjust the qualities of the available soil in order for it to match the design criteria. A cost-effective solution would be incorporated to convert locally available problematic base material into adequate construction material. This requirement has led to the development of soil stabilization techniques. The cementing method for stabilization of soil [1][11] is a well-established method of improving base used as a sub-grade for roads and pavements. Soil stabilizers such as cement, lime, fly ash, rice husk ash, furnace slag, and others are widely used for a long time, either alone or in combination.

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When these Pozzolanic materials [2] are added to clayey soils, they react with lime, producing a cementious compound. As a result, in addition to traditional cement, various commercial stabilizers have been discovered in recent years. Hence, it is necessary to compare the performance of these various contemporary commercial stabilizers to that of the conventional stabilizers used in cementing methods. In accordance to this, the current study attempted to compare the performance of three of the industrial commercial stabilizers namely; Zycobond and Terrasil produced by Zydex industries [35] and Alccofine manufactured by Count Microfine Pvt. Ltd. [37], to that of traditional stabilizers, cement and others as described above.

1.1. Evolution of Soil Stabilizing Methods

Clayey soil covers around 23% of India's total land area, largely in the central region of the nation, and these deposits can be found up to a depth of 3.7 meters in most areas. For a long time, fly ash, furnace slag [14], ash of rice husk, cement, lime [4][9], or a mixture of more than one admixture have been the most often used admixtures for stabilizing clayey soil [12]. Due to the availability of Pozzolanic minerals (SiO_2 and Al_2O_3) in these waste materials, these are added; to increase stability and make soil conditions favorable for construction. The essential notion behind employing these materials to improve clayey soils was the Pozzolanic reaction that occurs when Pozzolanic compounds contact with lime [13]. When Pozzolanic minerals are introduced to clayey soils, they react with lime supplied as an additive to form a cementious compound. This chemical reaction occurring between lime and Pozzolanic materials is responsible for the enhancement of clayey soil properties.

Soil stabilization technologies that use locally available, less expensive materials have a lot of potential for lowering pavement construction costs. However, numerous developmental operations need the usage of these areas, which do not have the desired engineering features. The most common application of soil stabilization methods is in the construction of sub-bases and subgrades for roads. The weak soil and, as a result, the CBR values are still being worked on. Engineers have experimented with several approaches to stabilize soils whose strength and stiffness attributes fluctuate as a result of moisture content fluctuations over time.

Soil stabilization is a method of enhancing the soil’s engineering properties. Thermal, electrical, mechanical, and chemical means of stabilization can all be used. The first two methods aren't utilized very often. Chemical stabilization entails mixing or injecting chemically active chemicals like calcium, lime, sodium chloride, fly ash, Portland cement, etc. into the soil, as well as viscoelastic materials like bitumen. Because they react with soils to generate cementing chemicals, these additives are classified as chemically active additives.

The conventional stabilizers, like Portland cement, hydrated lime and Fly ash; and the contemporary stabilizers, can be split into two categories. Fly ash, Lime, Portland cement as well as slag from blast furnace, are the most commonly utilized chemical additions. To improve soft soils and grounds, cement stabilization has been frequently used. The qualities of cement stabilized soil have been the subject of numerous studies. The major goal of this study is to analyze the outcomes of these studies for soft clayey soil's CBR characteristics. The main goal of this study is to see how Alccofine, Zycobond and Terrasil affect the geotechnical qualities of soft clayey soil; especially CBR.

1.2. Need and Advantages

The idea behind pavement and their design needs here is that every layer will reach a recommended minimum structural strength, resist shearing due to impact and dynamic loads, prevent dangerous deflections that might cause fatigue and cracking within the stratum or in the layers, and avoid any undesired permanent deformation due to densification. As the surface's quality increases, so does its capacity to distribute stress and strain due to load over a broader area, allowing for a drop in the pavement layer's minimum thickness. A few of the features of soil changes when mixed with admixtures are listed below-

1.3. Quality Amelioration

After adding additives, the engineering properties of soil will change. Soil characteristics such as analysis of soil grain size, reducing swelling potential and plasticity index, and boosting the soil's bearing ability, all have improved. In wet conditions, stabilization can also be used to provide a stable base for building operations. This kind of soil quality enhancement is called "soil stabilization." Pavement layers eventually get advantage from stabilization since it improves the properties of pavement and road materials. The qualities that were observed by enhancing the soil properties by stabilization are:

- Even after they've been drenched with water, they maintain a significant amount of their strength.
- Soil erosion resistance improves.

- The stabilized layer cannot be contaminated by materials in the supports layer. It reduces the number of deflections.
- The granular strata elasticity above the stabilized layer enhances remarkably.
- When the material is too damp or feeble, and removal really isn't cost-effective, hence; the stabilized layer can be used as a cover layer or working platform.

1.4. Thickness Reduction

Adding of different additives to the soil laminas, may improve the durability and strength of the soil surfaces and sub-surfaces, allowing stabilized material to be thinner than untreated material.

Soil Stabilization in General can be Summarized as

- Increases the loading capacity (CBR) of local road construction soils
- Improves structural strength and integrity
- Reduces penetration of moisture
- Provides a longer life-cycle for the road base
- Lower maintenance expenses
- Lower construction costs for roads and pavements

2. Tests for Clayey Soils

2.1. California Bearing Ratio Test

The California Bearing Ratio is a mechanical test developed by California State Highway Department, USA which compares the force applied per unit area needed to pierce a mass of soil with a standard piston; circular in shape at a rate of 1.25 mm/min to the force needed to penetrate a material set as standard at the same rate. The California bearing ratio (CBR) test was created to evaluate the mechanical properties of road subgrades and base material. The CBR test was devised to assess overall load-bearing capability of soils used in road construction. It is also used to determine the strength of the land on which the road or pavement will be constructed. The CBR test is a technique of putting a number on this intrinsic nature of soil; the test is carried out in a consistent manner so that we can evaluate different subgrade materials with respect to their strength and use these values to build the road or pavement.

2.2. Triaxial Test

Tri-axial test involves application of stress to a specimen of the test material in such a way that stresses along one axis differ from stresses in two orthogonal directions in a tri-axial shear test. This is commonly accomplished by sandwiching the specimen between two parallel base plates that produce stress in one direction and subjecting the specimen to fluid pressure impart stress in orthogonal directions. Under this testing, shear stress develops in the specimen when varied compressive stress are applied in the test device; loads are raised and deformations are observed until the specimen fails. Surrounding fluid is pressurized, and stress on the base plates is raised until the specimen in the cylinder fractures and generates shear bands, which are called the sliding zones within the cylinder. In the tri-axial test, the shearing action causes the sample to get shorter with specimen to protrude out across the sides. The platen's stress is relieved, and the fluid pressure brings the sides back in, forcing the specimen to grow higher once more. This process is repeated several times while gathering data on the sample's stress and strain. Bishop's pore pressure apparatus can be used to measure the pore pressures of gases and fluids in the specimen subjected to the test.

2.3. Unconfined Compression Strength Test

Commonly known as UCS, the Unconfined Compression Test is a standard lab test that determines the unconfirmed Compressive Strength of a soil or rock sample. The highest axial compressive load that a sample may tolerate under zero confined stress is known as unconfirmed compressive strength. The UCS test is also called as the Uniaxial Compression Test since load is delivered along a longitudinal axis. UCS is a frequently used measure in geotechnical design; however, it may not truly depict the strength. Other variables, including weathering, faults and discontinuities have a significant impact on the rock mass characteristics on a massive scale. In addition to the axial load, lateral and axial deformation is usually monitored in the test to determine the Poisson's ratio and elastic modulus of the sample. Before the sample is placed in the testing chamber, the two plates must be cleaned thoroughly. In the instance of a stress-controlled load device, the load should be provided continuously at rate of 0.5MPa/s to 1.0MPa/s, and failure should occur in around 10 minutes. An electronic instrument with the proper accuracy standards can be used to monitor and log stress and deformation readings. Within accuracy range of 1 percent, the maximum load is measured in Newton's.

3. Literature Review

Amu et al. (2005) investigated the use of a cement-fly ash combination to stabilize clayey soil. Tests on various parameters such as OMC, MDD, CBR and UCS were performed on three different classes of sample.

- 12 percent cement sample
- 9 percent cement with 3 percent fly ash, and
- Natural clayey soil sample

When compared to samples stabilized with 12 percent cement, the soil sample stabilized with a mixture of 9 percent cement and 3 percent fly ash performed better in terms of shearing resistance, CBR, MDD and OMC indicating the role of fly ash in ameliorating the stabilizing properties of cement on soft soil.

Degirmenci et al. (2007) investigated the use of phosphogypsum in conjunction with fly ash and cement to stabilize soil. On phosphogypsum, fly ash and cement stabilized soil samples, unconfined compressive strength, Atterberg limits and standard Proctor compaction tests were performed. Treatment with cement, phosphogypsum and fly ash decreases the plasticity index as MDD increases with phosphogypsum and cement concentration, but increases with fly ash content. With the addition of cement, phosphogypsum and fly ash, OMC reduced and the UCS increases. BC Soil was evaluated using three different stabilizing agents, according to Gundaliya.P.J. and Ozaa.J.B (2013).

- Waste cement dust obtained from the cement factory
- Lime powder and waste cement dust

Powdered lime - A best agent as a stabilizer was determined to be cement waste dust, which improved the Atterbergs Limit resulting in improvement in Plasticity Index of Black Cotton Soil and its compressive strength.

Tests carried out with three different percentages of three phases, each rising to 9 percent from 1 percent. With stage no. 1, the Black cotton soil behavior in the region of Rajkot was ameliorated, and the amount of Cement dust in Black Cotton Soil was found to be the optimum. In the second stage, a mixture of cement dust and lime powder shows an improvement of 8%. At 9 percent Lime powder in BC Soil, the third step produced the greatest results. After getting findings in the lab under normal settings, they decided to employ cement dust as a stabilizing ingredient in order to increase the Plasticity Index of Black Cotton soil in comparison to the other two combinations.

The behavior of BC soil with and without chemical stabilizer was investigated by Lekha B.M, et al. (2013) [21]. Terrasil was utilized as a stabilizer in various doses and was treated for seven, fourteen, and twenty-eight days. The mass of soil densifies as a result of the chemical reaction, reducing gaps between particles and making the soil surface impenetrable. Scanning Electron Microscope and X-Ray Diffraction were utilized to investigate the chemical compositions and microstructures of soils, respectively.

Chemical compounds present in soil such as feldspar, quartz, dolomite, montmorillonite, calcite, kaolinite, and other common to allcofine [20] react with chemical compounds found in various chemical stabilizers, according to Keerthi.Y, et al. (2013), who investigated the stabilization of soft soil admixed with cement kiln waste. Soil with varied qualities is combined with Cement Kiln Dust in various amounts, and metrics like as moisture and dry density are determined. Following a review of the data, optimal values were found at a 50 percent proportionate mix of CKD in the overall percentage.

Aparna Roy (2014) looked at how varied percentages of tiny amount of cement and Rice Husk Ash of cement stabilized high plasticity soft soil. Characteristic changes of soil, such as CBR, MDD, UCS and OMC are monitored. The results suggest that increasing the Rice Husk Ash concentration raises OMC while lowering MDD. The UCS value and CBR of soil are also significantly enhanced when RHA is present. Based on the largest increase in strength, 10 percent RHA content with 6 percent cement is indicated as the ideal level for actual applications based on the huge increase in soil CBR Value.

The efficiency of employing lime-palm oil fly ash mixes in clayey soil stabilization was researched using laboratory tests to determine the California Bearing Ratio (CBR) value by Norazlan Khalid et al. (2014). These additives are a very fine ground waste product from the burning of palm oil fibers. According to ASTM C618, the POFA utilized is classed as Class-F fly ash, which is defined as aluminous and siliceous elements with no or little cementious value. For the Pozzolanic reaction, as an optimal value, 6 percent hydrated limes were selected in investigation as an addition to different percent mixes of the POFA. Results showed that combining 6% lime with 3% POFA resulted in a better CBR value in both drenched and unsoaked conditions. It demonstrates that POFA may be employed as stabilizers for soft soil subgrades.

Jeevan Singh and his colleagues (2018) The following results were drawn from the laboratory tests, with the percentage of silica fume set at 20 percent and Alccofine percentage ranging from 0%, 5%, 7%, and 10%, respectively. As the amount of admixture added to red soil rises, the optimal moisture content increases but the maximum dry density drops. 2) Adding the combination to the red soil significantly enhances the saturated CBR. Adding of 20 percent silica fumes and 10 percent Alccofine to Red soil boosts CBR value by around 70%. 3) The UCS of stabilized samples improves dramatically to 180kN/m2 from 160.0 kN/m^2, a gain of nearly 20%.

Using Fly Ash and Alccofine for Sustainable Soil Stabilization, Lovedeep S. Sambyal et al. (2018) investigated the properties of clayey soil. In the case of clay soil, the liquid limit raised from 45 percent to 88 percent. The free-swell index decreased to 9.5% from 20%. The soil shrinkage limit for clay soil was raised to 18 percent and 28 percent, respectively, from 9 percent for unstabilized soil. When a percent mixture was added to the soil, the MDD rose from 19KN/m^3 to 21.5KN/m^3. With a percent mixing of 14 percent, the OMC dropped sharply to 7%. The value of undrained cohesiveness of soil combined to soil increased to 35.5kN/m^2 from 30 kN/m^2.

Neha Pundir et al. (2017). In this experiment, the burnt brick powder is used instead of soil in various percentages (10%, 20%, 30%, 40%, and 50%) and tests are conducted after curing for 7 days. The test findings show that increasing the amount of burnt brick dust in clayey soil reduces soil swelling, lowers OMC, and raises MDD. At 50% soil replacement with burnt brick dust, the OMC and MDD are 11.9 percent and 19.64 KN/m^3, respectively. The CBR value rises as the proportion of burned brick dust rises. The CBR value is 10.72 percent when 50 percent of the soil is replaced.

Nikhil Tiwari and his colleagues (2018), A study is carried out to investigate the influence of over-burnt brick powder on the building qualities of black cotton soils. The qualities of expanding soil coupled with Burnt Brick powder and lime are determined to be boosted. With raising the quantity of brick dust from 10% to 50%, the liquid limit of black cotton drops to approximately 29%. The plastic limit has been reduced from 17 percent to 11 percent. The plasticity index decreases as the proportion of brick dust increases, nearly halving from 17 to 26 percent. The moisture content decreases from 18.8 to 11.1 percent, while the dry density increases by 1.7 to 1.9 percent. CBR readings can increase by up to 8%. Figure 1 and 2 shows the soil treated only with Terrasil and a mixture of Terrasil and Zycobond.

Figure 1 Soil treated with Terrasil alone

Figure 2 Soil admixed with Terrasil & Zycobond

Lu Jiang et al. (2004) studied the effects of cement and GGBS on the stability of excess soft clay. Slag added to cement resulted in better strength and a longer cure time than cement alone. The strength qualities are calculated by adding ten percent, fifteen percent, twenty percent, and thirty percent cement to the dry soil weight. A clay sample combined with 10% cement and GGBS of 10%, 15%, and 20% of dry soil is maintained curing for 7,14,28 days, while another clay sample mixed with 15% cement and GGBS of 10%, 15%, and 25% is kept curing for 7,14,28 days. The results of the tests demonstrated that slag can partially substitute cement in the stabilization of soft clays.

The combined influence of cement and rice husk ash on engineering characteristics of BC soil was examined by Ramakrishna and Pradeep Kumar in 2006. RHA was increased up to 15% in 5 percent increments, while cement was increased up to 12% in 4 percent increments. The flexibility of the expanding soil was decreased using RHA and cement.

After 4 percent cement addition, the dry density of the soil rose slightly as the OMC raised. With an increase in the amount of cement and rice husk ash mixtures, soil MDD dropped and OMC rose. The UCS of BC soil rose linearly with cement addition up to 8%, while strength rate decreased at 12%. With the addition of cement and RHA, the soil's wet CBR was observed to be enhanced. With the rise in CBR rate, similar tendencies to those seen with UCS were seen. CBR value of soil was 48.57 percent at 8% cement concentration, and with a proportion of cement and rice husk ash mixture at 5%, 10%, and 15%, the values were 54.68%, 60.56%, and 56.62%, respectively.

4. Material Characterization

Clayey soil, Alccofine, zycobond, and Terrasil were used in the current study. The next sections discuss the properties of these materials.

4.1. Clayey Soil Characteristics

The term “Soil” has a variety of meanings. For engineering reasons, soil is described as a loose or moderately cohesive natural collection of mineral grains that is both inorganic and organic in origin. Soil is characterized by geologists as disintegrating rock, while soil is defined by agriculturists as the loose mantle at the earth's surface that promotes plant growth. Soil is formed through chemical or physical weathering of solid rocks, which can be metamorphic, igneous or sedimentary in nature. General physical property of soil is presented in Table 1 and the chemical structure of clayey soil and its affinity towards water has been shown in Figure 3. Due to presence of OH groups present at top surface of soil; the surface is highly hydrophilic in nature.

Table 1 General properties of the Subgrade Soil

No.	Property	Value
1	Plastic Limit (%)	35.4
2	Liquid Limit (%)	60
3	Silt Size Particles (%)	43
4	Sand Size Particles (%)	31
5	Clay Size Particles (%)	30
6	Gravel Size Particles (%)	0
7	Plasticity Index (%)	25.2
8	Specific gravity	2.5
9	Differential Free Swell (%)	90
10	OMC (%)	16.4
11	MDD (g/cc)	1.72
12	CBR Soaked (%)	2.2
13	CBR Unsoaked (%)	2.7
14	UCC (kg/cm^2)	1.82
15	Parameter Value Classification as per IS:1498-1970	CH

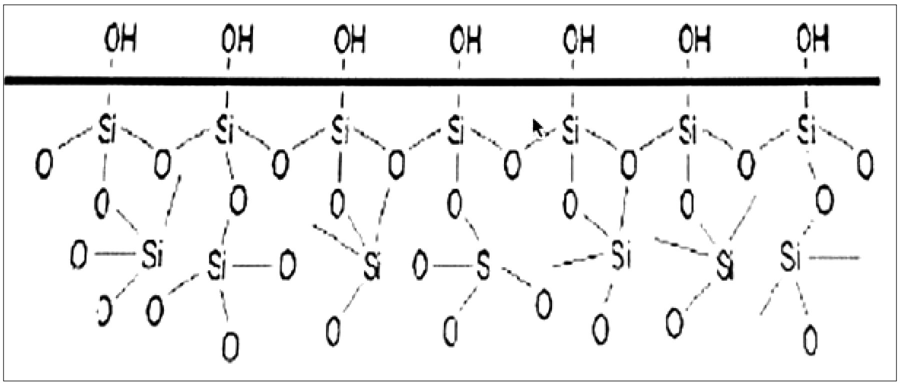

Figure 3 Chemical structure of soil and its affinity towards water

5.2 Alccofine Characteristics

Alccofine is a light grey dry powder made from very fine cementious GGBS (Ground Granulated Blast-furnace Slag). It is made out of high-glass-content slag with a high reactivity. The product employed in the previous studies was Alccofine 1108 and 1203, a cementious micro-fine injection grout made by Count Microfine Products Pvt. Ltd. for soil stabilization (Figure 4 and 5).

Figure 4 Alccofine1108 & Alccofine 1203 product samples

Figure 5 Alccofine powder

Alccofine is a modern micro fine substance with a particle size significantly smaller than existing binding materials developed in India, such as cement and fly ash. Because of its tailored particle size distribution, Alccofine offers unique qualities that improve 'concrete performance' in both fresh and hardened phases. It's a good alternate to Silica Fume since it has a good particle size profile that's neither very coarse nor very fine. Alccofine 1101 and 1203 are two different varieties of Alccofine with different content of Calcium Silicate.

Alccofine 1101 (Alccofine): It has high calcium silicate content. It's a fine-grained cementious grout for stabilization of soil and anchoring of rocks. All other admixtures utilized in India are pale in comparison to Alccofine performance. Due to high amount of calcium oxide (Cao), the product has excellent penetration in soil voids due to its high fineness. Table 2 shows the characteristics of the chemical stabilizer Alccofine

Table 2 Physical and chemical properties of Alccofine

No.	Property	Description
1	Specific Gravity Bulk Density (kg/m^3)	2.9-3.0
2	Fineness (cm^2 /gm)	Above 8000
3	Particle Size Distribution (μm)	2.5-15
4	Bulk Density (kg/m^3)	600-700
5	MgO content	8%
6	SO_3 content	3%

4.2. Zycobond Characteristics (ZB)

Zycobond is an acrylic co-polymer dispersion used for soil that provides erosion resistance and the property has been presented in Table 3. It is a sub-micron acrylic emulsion for soil particle bonding with a long life of over ten years. It provides water resistance and prevents water from entering through unpaved areas such as shoulders and slopes. Zydex Industries is the company that produces it.

It's mixed with the Terrasil and sprayed on hardened soils. It improves the quality of the soil strata, regulates soil disintegration, and helps to reduce maintenance costs by allowing soil layers/earth roads to dry quickly after rain.

Table 3 Lists the characteristics of the chemical stabilizer Zycobond.

No.	Property	Description
1	Color	Milky white
2	Odor	None
3	Ignition temperature	Above 200^{o}C
4	Flash point	Above 100^{o}C
5	pH value	5-6
6	Water solubility	Dispersible

4.3. Terrasil Characteristics (TS)

Terrasil is water soluble and 100 percent organosilane admixture based on nanotechnology. It is UV and heat stable liquid and very reactive to soil; able to impart desired modification for waterproofing of soil subgrades. It is manufactured by Zydex industries. Terrasil helps to stabilize and waterproof the subgrade. It's a green technology that uses the least number of aggregates possible. It combines with hydrophilic silanol groups found in silt, sand, clay, etc. and aggregates to produce very stable hydrophobic alkyl siloxane linkages, resulting in a breathable but water repelling membrane. It solves the most pressing subsurface challenges. Table 4 shows the characteristics of the chemical stabilizer Terrasil.

Table 4 General properties of Terrasil

No.	Property	Description
1	Colour	Pale Yellow
2	Specific gravity	1.01
3	Viscosity	20-100 cps
4	Flash point	Flammable at 12°C
5	pH value	5-6
6	Water solubility	Makes transparent solution

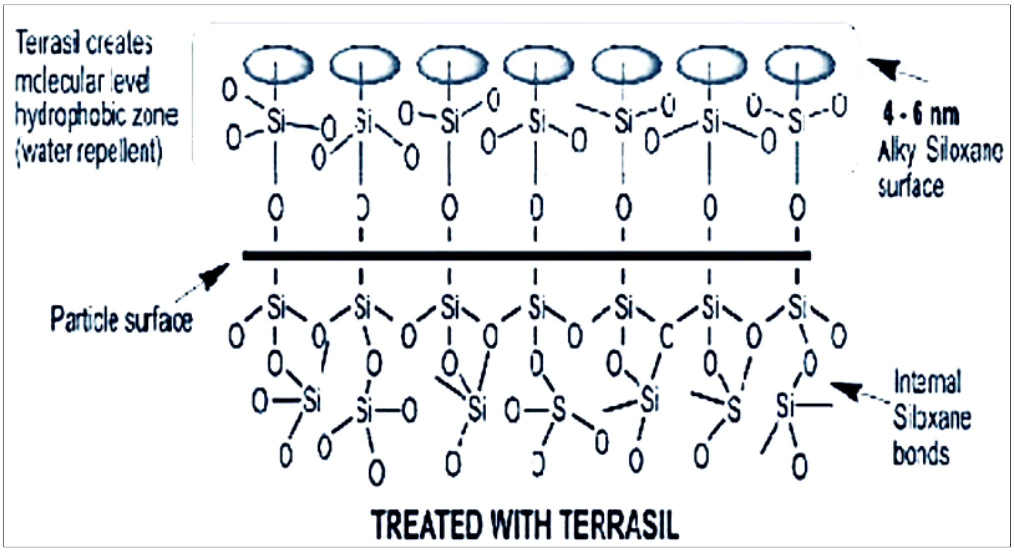

Figure 6 Hydrophobic zone created by Terrasil

Figure 6 demonstrates the chemical activity of Terrasil on soil to make a permanent hydrophobic film on top surface of soil.

5. Conclusion

Many studies have been done separately by mixing Alcofine with lime; Zycobond with Terrasil with lime in different proportions. Moreover, many other conventional additives such as rice husk, lime, cement kiln dust, etc have been tested along with time admixed with Zycobond and Terrasil to improve soft clayey soil's properties desired for construction. These studies clearly show the positive outcomes of such admixing and have been implemented for decades.

But no study reports mixing and testing of all three industrial products named Alccofine, Zycobond and Terrasil altogether. Hence, new possibilities for further experimentation incorporating all three contemporary admixtures with much more effective results still await. Moreover, the studies were carried out with soil samples obtained from different locations. But with geographical location change; properties of the same soil type may vary substantially. So, a need arises for more deep study at different locations.

Compliance with ethical standards

Disclosure of conflict of interest

The authors of the current work do not have conflicts of interest.

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