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Strengthening of Expansive Soil with Different Nontraditional Soil Stabilizers

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Abstract: Researchers are still seeking for the best soil stabilizers to solve difficulties that arise in expansive soils, while also considering cost and environmental impact. This research was based on expansive soil stabilization using nontraditional Stabilization because traditional soil stabilization is more expansive in transportation and has pollution challenges. Expansive soils are ineffectual because of their shrink-swell tendency, water content, high permeability and compressibility, and low shear strength. Expansive Soil failures cause many problems such as excessive settlement, substructure failure, and damage to the superstructure. Methods for improving soil properties are discussed in this paper to reach the goal. Ionic, lignosulfonates, salts, enzymes, polymers, tree resins, and petroleum resins are the nontraditional soil stabilizing agents discussed. For this research, a nontraditional stabilizer had a significant impact on improving soil stability. Therefore, this paper recommends future research to enhance the implementation of non-traditional stabilizer mechanisms in specific engineering applications.

Keywords: Expansive Clay Soil, Permeability, Nontraditional, Strength, Stabilization, Improvement

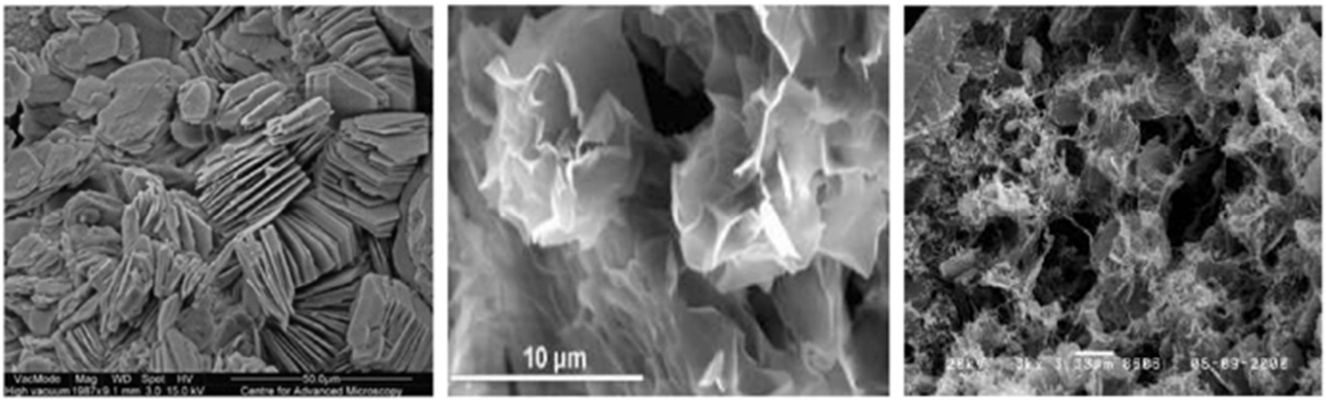
1. Introduction

Stabilizers that have been around for a long time are still widely used today. Lime, Portland cement, and fly ash were used occasionally as a soil-stability method. Because of excess moisture, the calcium-based stabilizer causes the stabilized sulfate-rich soil to react and take from calcium sulphone aluminate (Ettringite or Thaumasite), which occupies larger than the sum of the reactants' and stabilizer's volumes [1-3]. Nontraditional soil stabilization is a civil engineering building technology with low-cost advantages, ease of construction, local materials, and environmental protection; it is safe for human and animal populations and plants, nature, and the environment and may speed up vegetation growth. The construction of roads, airports, buildings, and water conservation systems all depended on this type of foundation material [4]. It is possible that the volume and structure of the soil could be affected by the presence of water [5].

Trying to predict the behavior of expansive soils when they are subjected to variations in moisture can be challenging. This is a significant roadblock to their use in infrastructure construction. Because it is frequently unsaturated and contains montmorillonite clay minerals, expansive clay soil is the most challenging soil in the presence of water because of its swelling and shrinking potential [6].

Damage caused by clay soil shrinkage and swelling in the United Kingdom is estimated to be around £400 million a year, $15 billion in the United States, annually, more billions of dollars are spent worldwide [7]. Engineering in expansive soil stabilization aims to normalize volume change and plasticity or workability while also improving strength properties significantly for the benefit of the soil. Enhance the physical characteristics of the expansive clay soil and its strength and deformation by using a novel nontraditional soil stabilizer that has never been used before. Using a nontraditional stabilization soil has environmental advantages and improves soil strength [8]. When this approach is used during construction, it is known to cause damage to shear strength, permeability, and excessive settlement. The clay in expansive soil has high plasticity, making it ideal for expanding crops. Expanding clay minerals like montmorillonite and illite are responsible for the soil's expansion. Increasing expansive soils' hydrophilicity and mechanical properties can significantly impact highway engineering, embankment stability, and cost savings. It is necessary to meet engineering construction safety requirements when working on large expanses of expansive soil while also improving the soil's capacity to absorb water and decreasing the amount of water that can expand [9].

Clay minerals aluminum silicates are alumina octahedron and silica tetrahedron, the two basic building blocks. Figures 1a and c show that kaolinite and illite are mostly inert and impenetrable, whereas montmorillonite causes the most expansive soil problems because of its strong bonding in water. But when water is present, the montmorillonite layer bonds are weak and easily broken Figure 1b, causing the soil to expand as water retention increases in the soil mass shown in Figure 1. It is well-known that the black cotton soil (BCS) has a more significant volume change tendency and is an expansive soil [10, 11], the majority of which can be found in places with lacustrine or basaltic geology, such as the Lake Chad basin or India Montmorillonite, which dominates its clay fraction, is responsible for BCS's ability to expand [12, 13]. It expands and hardens when the black cotton soil is wet during the rainy season. Cracks of up to 1 meter deep and 10 to 15 cm wide appear in the soil during the hottest months of the year, when the soil loses moisture and contracts [14, 15]. By managing volume change and plasticity, this research intends to considerably enhance the strength qualities of expansive clay soil. As a result, this research aimed to find how nontraditional soil stabilization was successful soil stabilization of expansive soil.



(a) (b) (c)

Figure 1. *Electron microscopic scanning of the main groups of clay minerals (a) Image of kaolinite crystals. (b) Image of montmorillonite. (c) Image of illite [46].*

2. Soil Stabilization

Soil stabilization can enhance mechanical strength, durability, compressibility, permeability, and plasticity [16, 17]. Over the last century, stabilization methods and additives have evolved significantly [18]. When the present soil cannot carry the planned structural load, soil reinforcement is required. In earth structures, soil stabilization reduces permeability and compressibility while enhancing soil shear strength [7, 19-20]. As a result, there is a lower possibility of structural settling occurring. In soil stabilization, stabilizing agents (binder materials) are introduced into porous or soft soils to enhance their geotechnical properties, such as compressibility, strength, permeability, and long-term durability [21]. A variety of factors contribute to soil stabilization, including the chemical composition and mineralogy, as well as the amount of organic matter, salt content (mainly sulfate), Cation Exchange Capacity (CEC), acidity (pH), and Specific Surface Area (SSA) [22]. Stabilized soil properties can also be affected by the type and duration of curing conditions and the building methods and quality (compaction effort).

3. Stabilization Techniques of the Expansive Soil

Mechanical and chemical approaches are often used to stabilize expansive soils. Various methods can stabilize the soil; it is possible to categorize these methods into two main groups: Mechanical and chemical stabilization methods. A soil property can be improved by altering its gradation through mechanical Stabilization [23]; the physical-synthetic environment around and within clay particles is changed so that the earth requires less water for static balance and makes it more difficult for the framework water to enter and exit the framework to meet specific design road ventures [23]. Using chemically stabilized soil for mechanical reinforcement may help improve soil properties such as tensile strength and stiffness.

3.1. Mechanical Stabilization

Stabilizing soil by altering its gradation is called mechanical Stabilization. Vibrational methods, such as using rollers or rammers to compact the soil, are also used to achieve densification, as is blasting [24]. This approach, which relies on the soil inherent properties, is used to gauge its stability. Combining two or more natural soil types can create a composite material that outperforms the components [25]. To achieve mechanical Stabilization, two or more soil grades are mixed to produce a material that meets the desired specifications.

3.2. Chemical Soil Stabilization

To improve the engineering properties of the soil, chemical stabilization is accomplished by blending and mixing chemicals with the soil. Particle composition and chemical/reaction stabilizers work together to determine how well soil is stabilized [26]. By combining a range of materials, soil characteristics such as hydraulic conductivity, swelling potential, compressibility, and volume change properties can be modified to the desired degree [27].

4. Characterization of Expansive Clay Soil

The Atterberg limits, particle size distribution, moisture content, and dry density of expansive clays have all been determined through laboratory experiments [28]. Explosive soil behavior and various laboratory methods to identify it are explained in depth in these studies. To detect clay minerals with growing lattice structures in natural soil, the criteria for determining the presence of these minerals can be divided into two categories: methodological approaches to mineral identification and inference [29].

4.1. Mineralogical Identification Methods

X-ray diffraction, dye adsorption, differential thermal analysis, scanning electron microscopy, and chemical analysis are analytical methods [30]. To get the best results, these methods should be used in conjunction. Research laboratories are the only places where these techniques can be used because they require expensive specialized equipment and expert interpretation of the results.

4.2. Inferential Testing Methods

Inferential testing methods include direct methods for calibrating index properties such as shrinkage limit, liquid limit, and particle size distribution, as well as indirect methods such as the oedometer test and free swell tests (free swell value, differential free swell, and free swell ratio), which are all examples of inferential testing methods [30].

4.2.1. Indirect Methods

Examples of soil index attributes used indirectly to determine the potential for soil swell include liquid limit, shrinkage limit, and percentage clay size composition. The liquid limit in a laboratory is often determined using either Casagrande traditional technique or the fall cone method. For soil to flow and close a standard-width groove, a certain amount of water must be injected [31]. Geotechnical engineering literature includes several classification algorithms for forecasting the likelihood of soil swell based on fine-grained soil liquid limit. Table 1 illustrates that when soil reaches a specific water content, it becomes plastic, determined by the difference between the liquid and plastic limits. There are various methods for determining soil expansion based on the soil plasticity index, as shown in Table 2. The following disadvantages of using indirect methods to assess soil swell potential: The liquid limit is one criterion used to identify and classify expansive systems Table 1 [32, 33]. Plasticity index Table 2. Because of their inherent limitations, mineralogical identification methods can only identify clay minerals in expansive soils, but they can still characterize swelling behavior. Mineralogical identification methods have been argued not to be cost-effective because of the high instrumentation, complexity, and expert interpretation needed. This means mineral identification procedures are no longer applicable to various situations.

4.2.2. Direct Methods

Techniques in this area can directly measure the potential for soil swell.

Oedometer tests, Conventional oedometer swell tests provided the most accurate and valuable information about a swell potential. To classify the extent of soil extensibility, volume varies from air dry to saturated when the oedometer is submerged in water 7 kPa is used in Table 3. Soil expansion potential can be assessed using conventional oedometer swell tests. Under a vacuum, the total volume change in an oedometer from air dry to saturated is measured at 7 kPa and is used to classify the degree of soil expansivity. Free swell tests, slowly pouring oven-dried soil through a 425 m sieve, and recording the sediment reached its equilibrium volume is what the Free Swell Value (FSV) Test is all about. The percentage significantly rise in soil volume over the original volume calculates the free swell value. Using index properties and direct methods to estimate swell potential, the inferential testing methods appear helpful in identifying clay minerals and classifying swelling behavior [34]. The free swell index is defined by Eq (1).

$$\text{FSI (\%)} = \left[\frac{V_d - V_k}{V_k}\right] 100 \quad (1)$$

where Vd and Vk denote the equilibrium sediment volumes of 10 g. Soil samples were oven-dried and passed through a 425μm sieve. The soil FSI-based swell potential is classified using the guidelines in Table 4.

Scientists and engineers have extensively investigated soil development stabilizing processes, including mechanical, chemical, biological, and electrical. Soil engineering properties will be improved through chemical Stabilization in this investigation. Chemical Stabilization is commonly used to enhance soil physical and mechanical qualities. The traditional and nontraditional stabilizers are the two chemical stabilization types based on chemical-based stabilizers used. Soil stabilization using nontraditional stabilizers was the focus of this study [27, 35].

Table 1. *Expansivity soil classification is based on liquid limit [30].*

Swell potential	Liquid limit (%)		
	Chen	Snezhana	IS: 1498
Low	<30	<50	20-35
Medium	30-40	50-60	35-50
High	40-60	>60	50-70
Very high	>60	-	70-90

Table 2. *Soil expansivity classification is based on the plasticity index [34].*

Swell potential	Plastic Index (%)	
	Holtz and Gibbs	Chen
Low	<18	0-15
Medium	15-28	10-35
High	25-41	20-55
Very	>35	>35

Table 3. *Expansive soil classification is based on oedometer swell tests [34].*

Swell potential	% Expansion in oedometer Holtz and Gibbs	%Expansion in oedometer Chen
Low	<10	0-15
Medium	10-20	1.5-5
High	20-30	5-25
Very high	>30	>25

Table 4. *Expansive soil classification based on FSI [30].*

Swell potential	FSI
Low	<50
Medium	50-100
High	100-200
Very high	>200

Table 5. *Comparison between cement and polymer strength [59].*

	Variation in cement content			variation in polymer content		
Unconfined	20%	30%	40%	2%	3%	4%
compression	5.1	8.2	9.7	4.9	7.8	9.56
strength (MPa)	8.5	8.8	10.4	8.2	8.6	10.35

5. Types of Nontraditional Stabilization Additives

For legal reasons, the chemical composition of commercial stabilizers is not made public. To better understand the fundamental stabilization mechanisms of these products, it is helpful to categorize them as their major chemical components and the qualities they are expected to possess as reinforcements. In terms of nontraditional additives, there are seven different types: ionic, enzymes; lignosulfonates; salts; petroleum resins; polymers; and resins derived from trees [36, 37]. Secondary additives such as surfactants, catalysts, and UV inhibitors are common in many products. Stabilization mechanisms can be found in complementary additives, but the primary stabilization mechanism is the most common [3].

5.1. Ionic Soil Stabilizer

Ionic soil stabilizers have been used for decades; on the other hand, our understanding and in terms of their stabilization mechanism and effectiveness, there is a lack of experimental evidence. Liquid surfactant ISS is composed of active ions. Ionic soil stabilizers convert soils from hydrophilic to hydrophobic states, which lowers the surface tension, effectively reduces swelling, and improves soil engineering properties [38].

Reynolds developed ISS in the United States in 1959 and marketed it as the Reynolds Road Packer worldwide. It has now been used all over the world. Today, it is still in use. It has gradually spread to Canada, Mexico, Australia, South Africa, and many different countries 960s [39]. Ionic soil stabilizer is a chemical compound with multiple strong ions suitable for various soil types with a clay particle content greater than 25% [39-42]. After treatment with the ionic soil stabilizer, soil particles began to play a more prominent role in the ion exchange process [43]. The gap between soil particles was reduced, the structure was tightened, and the soil tensile strength, durability, and shrinkage qualities were all improved [44]. When clay was added to the sample at a dry weight of 50%, the investigators detected very small variations in the alumina/silica ratio.

A few modifications help scholars' theories on the ionic additive mechanism. ISS is considered environmentally friendly because it is non-toxic, non-polluting, and non-hazardous. As a result of its excellent air permeability and workability, this material is ideal for construction. As a result, only 0.01% to 0.03% of the stabilized dust by weight is produced [45]. On the other hand, this application field is so broad that it can be used for highway pavement stabilization, dam construction reinforcement, and building basement treatment. It is also easy to store and can be kept at room temperature for more than three years because it is non-flammable and non-explosive. In practice, engineers are reluctant to use them at all. Most roadblocks stem from a lack of published information about ionic soil stabilization. Despite the supplier's claim that ISS positively affects expansive soil behavior, the supplier continues to supply the field. Second, suppliers frequently alter the names of their products to avoid violating patents. A product's impact on the environment can be difficult to track over time, and laboratory tests may not accurately reflect field treatment conditions.

5.1.1. Improving Mechanism of Ionic Soil Stabilization

The resin itself is made up of a wide variety of ionic solids. Dissolving it in water allows you to separate cations from anions. With the incorporation of ISS, it is possible to physically and chemically replace the cations that are adsorbing on clay surfaces [41]. Soils that expand and contract unusually are known as expansive soils. By modifying the hydrophilic expansive clay soil components that cause swelling, shrinkage deformation can be minimized or eliminated to the greatest extent possible [46]. Another factor to think about when calculating the index is free expansion, a metric that directly reflects the expansion characteristics of the soil [42].

5.1.2. Factors Affecting the Strength of Ionic Soil Stabilized Soil

Max Knoll and Ernst Ruska invented the scanning electron microscope (SEM) in 1931, and they used electrons to conduct their research to build the equipment. An electron beam is focused vertically on the specimen [47]. Electrons and X-rays are emitted when a beam interacts with a vacuumed specimen. To create images, the detectors must collect X-rays and primary and induced electrons produced by direct electron interaction with the material. These signals must then be converted into signals and shown on a computer screen to create the final image.

5.2. Enzyme Stabilizers

For more than three decades, enzyme-based soil stabilization has been used successfully in road construction to alternative, more traditional stabilization methods. Enzyme stabilized unbound pavement has seen widespread use over the last three decades, but there is no universal standard or tool available to practicing engineers for evaluating its performance [48, 49].

Termites frequently use enzymes to stabilize the soil when creating mounds in tropical regions like Latin America, Africa, and Asia. When constructing mounds, termites adhere to soil particles together with saliva and feces. Increasing the organic matter, carbon, calcium, phosphorus, potassium, magnesium, and nitrogen in the soil enhances micro soil aggregation. This results in extermination sites for termites that are rock-solid and a few meters tall, able to withstand heavy tropical rains [37].

An enzyme acts as an organic catalyst to speed up a chemical reaction. Without an enzyme, the reaction would take longer. The fact that enzymes are not destroyed during the reaction and do not become part of the end product means that only a small bio enzyme is necessary to stabilize the soil [50]. These organic molecules can catalyze chemical reactions when the conditions are just right. An enzyme must move around freely in the soil to function. It takes longer for reaction products to spread to the reaction site because it is supplied by specific soil chemistry. After all, soil fluids are more plentiful in soils with higher organic matter contents. Soil enzymes continue to function until they can no longer perform any more reactions. Enzymes tailored to the soil should be used [51]. Clayey sand plasticity index is minimized by 11.2% at 400 ml/m^3, while the UCS at seven days raised by 30% [52]. When it comes to improving strength, enzyme-lime is superior to enzyme and lime alone. However, there are only a few studies showing that enzyme-stabilized soil does not significantly improve compaction, Atterberg limits, or strength tests [53].

5.3. Polymer Stabilizers

Many researchers are studying polymer-stabilized soils to better understand the characteristics to be expected in soils treated with polymers and the fundamental mechanisms that govern changes in engineering properties [54]. A polymer is a large molecule made up of repeating building blocks known as monomers. Polymers can be used in different geotechnical engineering applications, liquids, or fibers. The liquid polymer stabilizer can coat soil particles with microstructure elements, resulting in flexible connections [55, 56]. Many polymers have been studied as potential soil stabilization agents. They are three groups of polymers based on the structure backbones and the source of the polymer. Polymers include geopolymers, biopolymers, and synthetic organic polymers [57]. Soil stabilization, particle enhancement, strengthening, and maintenance are just a few of the uses for these polymers in civil engineering. Powder or liquid polymer is commonly used as a soil stabilizer. Diverse soil stabilization outcomes are obtained when using these materials [58]. There's a big difference in the amount of polymer needed to achieve the same results as traditional stabilizers like cement, as shown in Table 5 [59].

5.3.1. Characteristics of Polymers

For soil stabilization, polymers are utilized as glue, and the polymer binds soil particles together. Biopolymers and synthetic polymers are two of the most common polymers used in soil stabilization. Despite the fact that each polymer is unique, biopolymers are frequently more environmentally friendly than traditional soil stabilization methods, especially when compared to other methods. Various engineering polymers have advantageous qualities such as high strength or modulus to weight ratios (lightweight yet relatively stiff and strong), toughness, resilience, resistance to corrosion, lack of conductivity (heat and electrical), color, transparency, processing, and low cost. Numerous advantageous qualities of polymers are unique to them and are a result of their long-chain molecular structure.

5.3.2. Type of Polymers

(i). Geopolymers

Polymers made from amorphous aluminum silicates and activated by high concentrations of alkali are known as geopolymers [60]. Alkali concentration and binder-to-soil ratio adjustments increased geopolymer stability. Its capacity to tolerate acid and alkali corrosion is one of the most essential characteristics of geopolymer binder [61]. When it comes to subgrade structures, it's important to keep them stable and firm in colder regions [62]. When metakaolin and alkali activator concentrations rise in geopolymer-improved soil, brittle split failure occurs instead of plastic shear failure. Use this study's findings to set parameters for using and promoting metakaolin-based geopolymer binders in engineering soils [62].

(ii). Biopolymers

However, the physical properties of biopolymers can vary depending a lot on the kind of biopolymer and the composition of the biopolymer. This suggests that biopolymers may be helpful to soil-improvement materials [63, 64]. The biopolymer was selected in two stages, considering adhesion and cohesion properties. To put it another way: Cohesion is the intermolecular attraction that holds a body together. Cohesion is the resistance to an external force or tension that prevents the atoms of a solid from dissolving into smaller pieces. The physical and chemical forces that hold two surfaces together are known as adhesion; adhesion is not the same [65]. Depending on their structure, biopolymers can have a wide range of chemical functional groups, such as hydroxyl, ester, or amines. As a result of their structure with a long chain, the sites they provide have a greater variety of possibilities for chemical reactions specific to a given functional group structure. Chemical bonding describes the forces that hold soil particles and their surfaces to form cohesion. Forces determine the efficacy of microscopic adhesion at the particle-gel interface [66]. A phase interface is characterized by van der Waals forces and ionic/electrostatic or covalent bonding (chemisorption) (physical absorption).

Regarding bond energy in KJ/mol, short-range ionic/electrostatic and covalent bonds have the highest values, while ionic bonds have the lowest, which produces the best results. Dipole interactions within the bulk material make the strongest bond, Van der Waals forces, and have the weakest bonds over long distances [67]. Assuming that the cationic biopolymer is coupled with soil particles, the result would be significant electrostatic bonding throughout the treated ground because most natural soil particles have a slightly negative surface charge. To benefit nonionic biopolymers, it would be advantageous to use a chemical capable of creating hydrogen bonds with soil particles (still a strong chemical attraction force).

(iii). Synthetic Organic Polymers

Humans use various methods to construct synthetic organic polymers' main chains and side chains. Polymers can be divided into elastomers (including rubber), thermoplastics (polyethylene), or synthetic fibers. Polyacrylamide PAM, polyacrylate PVAc, and other synthetic organic polymers are commonly employed in soil stabilization [68].

5.4. Lignosulfonates

Organic polymer Lignosulfonate is made from lignin, a byproduct of the paper and wood industries. In the cement industry, for example, it is widely employed. As a soil stabilizer, Lignosulfonates have attracted the attention of numerous scientists [69]. No organic solvents can be used to dissolve the lignosulfonate salt. Its molar mass ranges from 4600 to 398,000 g, and its molecular weight ranges from 800 to 100,000 g.

Around 50 million lignosulfonates are produced worldwide each year [70]. There are numerous uses for lignosulfonates, including dispersants, concrete additives, flocculants, metal absorbents, dust suppression in mining, and anti-oxidant and fertilizer [71]. As a water agent, lignosulfonate draws soil particles together to produce a flocculate structure that increases soil strength by serving as a van der Waals force or secondary bonding force.

Lignosulfonate's effect on clayey soil was examined. Observing electrostatic interactions between the particles found that adding lignosulfonate to clays increased the specimen stiffness and UCS [72]. Lignosulfonate increased resistance and decreased permittivity in sand-clay compounds when water was substituted for some of it; thus, the most significant effects were found to be on the dry side of the optimal moisture content range [73]. It has been common practice to employ lignosulfonate to reduce fine road dust. It is possible that lignosulfonate could be used as an alternative to current soil stabilization practices to improve the specific soil engineering properties [36]. According to outcome obtained through a scanning electron microscope (SEM), lignosulfonate can form bonds among soil particles.

Characteristics of Lignosulfonate:

Lignosulfonate (LS) is a solid rubbish from the manufacture of paper that generates around 50 million tons worldwide each year [73]. Depending on the wood/paper industry, the LS can be extruded as calcium, magnesium, or aluminum-based organic compound depending on the wood/paper manufacturer (benzene ring as the primary body). The sector is currently tasked with finding the most efficient way to dispose of waste material. Due to well-documented scientific evidence, slope stabilization and sustainable infrastructure construction projects are expected to gain greater acceptance of LSs expansive-based soil improvement mechanisms of Stabilization [74]. LSs can compete with any other stabilizer regarding cost byproducts of different processes.

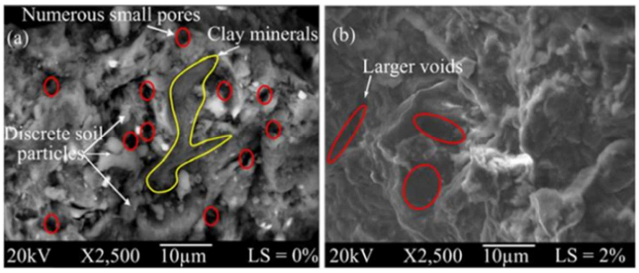


Figure 2. *SEM micrographs of (a) untreated (LS = 0%); and (b)treated (LS = 2%) expansive soil [59].*

It is also non-toxic and does not cause the host soil to become more brittle when used for Stabilization. In concrete, LSs cut CO_2 emissions by 14 kg of LS per cubic meter of concrete. Temperature changes do not cause LS to become insoluble or crystallize into sludge. The effectiveness of LS-based water-reducing admixtures is unaffected by differences in the content and quality of the cement mix. It is possible to achieve maximum compressive strength in concrete by using LS at LS amounts of up to 0.2 weight percent in cement, depending on temperature [75]. The compressive strength of the adhesive is reduced when LS is used in more significant amounts. Functions include set retardation, water reduction, and high range water reduction admixtures in the range of low, medium, and high Formulations for concrete admixtures requiring set retardation due to high ambient temperatures can use LSs [76]. Figure 2 shows how lignosulfonate microstructure analysis can bind soil particles together through chemical and physical means. Small pores can be seen in SEM images of soil that has not been chemically treated. One can reduce the number of pores in a large soil area by using 2% Lignosulfonates in the treatment process. Small pores in expansive soils can be reduced even though the LS content is only 2% [59].

5.5. Salt Stabilization

Salt stabilizers such as calcium chloride and magnesium chloride are frequently used ($CaCl_2$ and $MgCl_2$, respectively). Soils retain moisture because salts are hygroscopic, drawing water from their surroundings. To facilitate cation exchange, divalent cations must be added to the soil to facilitate the exchange of divalent cations from salt with monovalent cations in the soil. It is possible that cation exchange can help stabilize soil particles and diminution the capacity of soil layers to hold back the water. Particle spacing is reduced as a result of this, which enhances flocculation. As a result of the salt recrystallization process. The density of the treated soil has been improved. The presence of water in the pores reduces the physical links that hold soil particles together [77]. Increased pore water surface tension is another way salts improve soil cohesion and strength. As a result, salt stabilizers can improve soils in various ways. Because of their water solubility, salts are particularly harmful to metals and should be avoided.

Base aggregates for road construction or parking lot areas can be stabilized using "salt stabilization." Its ability to improve foundation soil hasn't been tested yet. Any type of table salt (sodium chloride) will do. Pure salt is unnecessary, and chemical impurities as low as 5 percent are not harmful. Typically, a 3/8-inch sieve filters coarse, crushed rock salt. One of the most challenging aspects of using salt-affected soils is ensuring that the soil retains sufficient permeability to allow salinity control and reclamation. In sodic soils, where exchangeable sodium frequently causes significant decreases in soil permeability, the problem becomes more pronounced when the salt concentration in the soil solution is reduced.

5.6. Petroleum Resin Stabilization

Various soil stabilizers use lignosulfonate and petroleum resin to bond different soil types and fly-ash particles, creating a waterproof surface and keeping fly-ash dispersion at bay over time [36]. For a long time, heat treatment has stabilized the soil. Traveling heater burners and the direct combustion of petroleum products in soil borings provide surface warmth in the winter months. Heating only works on fine-grained (clayey) soils as a soil treatment method. As water evaporates, chemical interactions between clay minerals continue for extended periods at high temperatures. However, heating has recently come back in limited applications, such as remediation of contaminated soils, due to rising costs and environmental concerns associated with petroleum products. Warming the soil to a working temperature aid in extracting volatile organic compounds (VOCs) from their natural environments. The extraction of soil vapors can be increased by pumping heated air or steam into polluted soil using injection wells [78].

5.7. Tree Resin Stabilization

Emulsions derived from tree resin (primarily from pine, fir, and spruce) for dust control and soil stabilization in unbound road paving are common. Because tree resins bond soil particles together, dust formation is reduced, making the emulsions excellent for this use [79]. Temperatures typically range between 100 and 200 degrees Celsius when applied at higher rates and mixed in greater depths. Individual soil particles are coated with tree resin emulsions to keep them together. Soil particles are held together by tree resins, such as lignosulfonates. Polymer emulsions, such as those derived from tree resins, are more effective in coarse-grained soils, but they are less effective because of the decreased mixing effectiveness in fine-grained soils. At least, in theory, water solubility is predicted for lignosulfonates and tree resins. While synthetic resins are more water-soluble than natural resins, experience has proven that natural resins are more resistant to leaching under moist situations. When mixed with Type I Portland cement, tree Resin 1 enhanced UCS in dry and wet conditions.

After 28 and 7 days of treatment, they found that adding tree resin to silty-sand soil increased its strength when tested in the rain. However, the strength increase was more minor than the polymer emulsions tested. There were no discernible differences between the treated and untreated specimens of a low-plasticity clay. Fiber stabilization treatments for poorly graded sand SP were tested on two tree resin products. In terms of tensile strength, both tree resins beat out untreated alternatives. Earlier studies have shown that tree resins are more differential than lignosulfonates but less prone to leaching, crediting the physical bonding process [80].

6. Conclusion

Soil stabilization techniques have been developed based on their physical and chemical features, which have led to a wide range of nontraditional methods. Experts are currently conducting research into the macrostructure of expanding and stabilized soils. Changing soil microfabric, pore size, and components are at fault. Chemical additives used in soil stabilization have been studied to determine the standard chemical processes between elements, compounds, and mixtures. Among its many geotechnical uses is building roads and embankments and dams and reservoirs.

1) Using an anionic soil stabilizer, the thickness of the hydrated layer and the gap between soil particles were both reduced. As the bonding effect became stronger, the structure became more compact.
2) In general, the OMC of an enzyme-stabilized soil is lower than that of an unsterilized soil, and enzymatic lime increases the soil's tensile strength more than enzyme and lime alone.
3) In civil engineering, polymer stabilization is used for various purposes, including soil stabilization, particle enhancement and strengthening, and maintenance.
4) The treated materials outperformed the untreated after 23 days of use with the lignosulfonate addition.
5) The absorption of water by salts in the soil keeps the soil moist, and surface tension increases particle size.
6) Tree resin emulsions might be employed to stabilize fines-rich subgrade or foundation materials. It is possible

to hire a soil stabilizer made of lignosulfonate and petroleum resin to create a waterproof surface that reduces the rate at which fly ash spreads. Therefore, this paper recommends future research to enhance the understanding of nontraditional stabilizer mechanisms, leading to improved product implementation for specific engineering applications.

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