



Improving The Engineering Properties of Expansive Clayey Soils by Adding Biopolymer-A Review

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ABSTRACT

Globally, expansive soils are mostly found in arid and semi-arid regions. These soils have a considerable potential for swell-shrinkage because of the presence of montmorillonite clay. Expansive soils experience swelling; they are also known as shrink-expand or swelling soils. when exposed to moisture, and when the moisture content drops, shrink. Because of their different wetting and drying characteristics, they cause structural damage to structures and pavements. Several stabilizers and techniques have been applied to stabilize the soil and make it more suitable for construction purposes. The main objective is the search for suitable soil stabilizers to address the challenges presented by expansive soils, not only in terms of their essential geotechnical features, but also in terms of both economic and environmental issues, an alternative Environmentally-friendly stabilizers termed as (Polymer) was used to treat expansive soils. This reviews some researches into the use of polymer and biopolymer in improving clayey soil, also their effect on soil swelling. It also discusses the suitability of these materials for future use and the extent of their impact on the environment.

1. Introduction

One of the more problematic soils that cause damages to a number of civil engineering structures is expansive soil. When compared to other types of soils, expansive soils act differently. Construction projects may encounter issues that result in damage, especially for lightweight structures, such as lifting buildings, fractures in walls and ceilings due to the expansive soil because of its swelling and shrinkage behavior [1][2]. It is a naturally

occurring, widely scattered, plastic soil that is mostly composed of clay minerals and is particularly sensitive to changes in water levels between the wet and dry seasons. [3]. Clay particles possess a significant surface area and the electrical forces exerted on their surface are more dominant than gravitational forces. In the rainy season, heave problems occur, as this soil swells and increases in volume when its water content increases [4]. Shrinkage issues arise during the dehydration period as a result of the

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decrease in soil water content ,cracks appear with a width of about 20 mm on

the soil surface[5] as shown in Figure(1)



Figure 1. Cracks due to the shrinkage of dry, expansive soil [6]

2. Identification of The expansive Soils

Soil swelling is primarily caused by two factors: the addition of water and unloading [7]. The degree of soil swelling is affected by the mineralogical composition and the distribution of particle sizes. The phenomenon of swelling and contraction of clayey soils due to changes in moisture levels poses significant challenges to infrastructure worldwide[8] . Historically, soil expansion has been responsible for over 50% of the damage caused to structures and infrastructure[9] . Therefore, it is crucial to possess an understanding of the soil's capacity for swelling and the techniques available for reducing this phenomenon in order to avoid unfavorable consequences . The swelling of the soils primarily occurs in the higher layers of the soil, where changes in transpiration have an impact on the soil , Hence, identifying the “active zone depth” becomes essential in expansive soils. The depth of the active zone refers to the specific depth at which the expansive soil experiences changes in water content that cause it to expand [10]. Expansive soils can be identified through the use of both direct

and indirect laboratory techniques. Direct tests entail the direct measurement of swelling potential of the soil , while indirect tests, involves (Atterberg limits), use the measurement of a related characteristic and are the most frequently utilized indicators of expansive soils. The accompanying techniques are frequently employed to ascertain expansive soils:

1. The swell potential (%) and the swell pressure (kPa) are direct techniques employed to calculate and quantify the magnitude of swelling soil. The use of one-dimensional swell tests is used to measure the tendency for swelling and the corresponding pressure exerted by the swelling, a process that requires more time compared to the measurement of Atterberg limits. A soil of less than 0.5% swell potential is classified as low expansive .
2. The liquid limit (LL) :Is the moisture content at which a soil changes from a plastic condition to a liquid one. It represents the soil's ability to hold moisture. As the LL increases, the

affinity for water becomes stronger, leading to a greater potential for expansion. A soil with a liquid limit (LL) below 50% is classified as having moderate swelling.

3. The plastic limit (PL): Refers to the moisture level at which the soil transitions from a semi-solid state to a plastic state. Plastic limit values result in a decrease in the plasticity index (PI), which is also used as an indicator of stability in relation to swelling. A soil with a plasticity index (PI) lower than 25% is classified as having poor expansion characteristics. Furthermore, a permeability index (PI) of 10% or lower is classified as an indication of a soil that is stable and does not experience expansion[11].

3. Swell potential and swell pressure.

Swelling pressure is an important indication of the potential for problems in expansive

soils. The pressure referred to here is the highest amount of force that must be exerted per unit of area in order to avoid an increase in volume of a swelling soil. A swelling pressure below 20 kPa may not be considered significant. The swell potential of a soil refers to the extent to which the soil expands when subjected to specific water content and loading Condition. Odometer tests specifically designed for this purpose have shown to be quite valuable in determining the magnitudes of these parameters for expanding soils[11] .

4. Classification of Expansive Soils

A classification system that uses metrics to determine the possibility for swelling based on the Liquid Limit (LL) and Plasticity Index (PI) values [12] is provided in table (1). Soil swell potential is categorized as low, marginal, or high.

Table 1. Classification of expansive soil from[12]

L.L %	PI %	Potential swell ,%	Potential Swelling Classification
>60	>35	>1.5	High
50-60	25-35	0.5-1.5	Marginal
<50	<25	<0.5	Low

Abduljauwad [13] reported a classification chart based on the amount and type of clay-size particles as illustrated in figure (2).

Sridharan [14] proposed a criterion known as the free swell ratio is utilized

to forecast the clay type, possible swell classification, and the prevailing clay minerals found in a specific soil. Table (2) provides the classification of expansive soil based on the free swell ratio.

Table 2. Expansive soil classification. based on free swell ratio[14]

Free swell ratio	Clay type	Potential swell Classification	Dominate clay mineral
≤ 1.0	Non-swelling	Negligible	Kaolinite
1.0-1.5	Mixture of swelling And non- swelling	Low	Kaolinite and Montmorillite
1.5-2.0	Swelling	Moderate	Montmorillite
2.0-4.0	Swelling	High	Montmorillite
>4.0	Swelling	Very high	Montmorillite

Free swell ratio: is the ratio of the equilibrium sediment volume of (10)g of oven dried soil passing (425) μm

sieve in distilled water to the carbon tetra chloride[15].

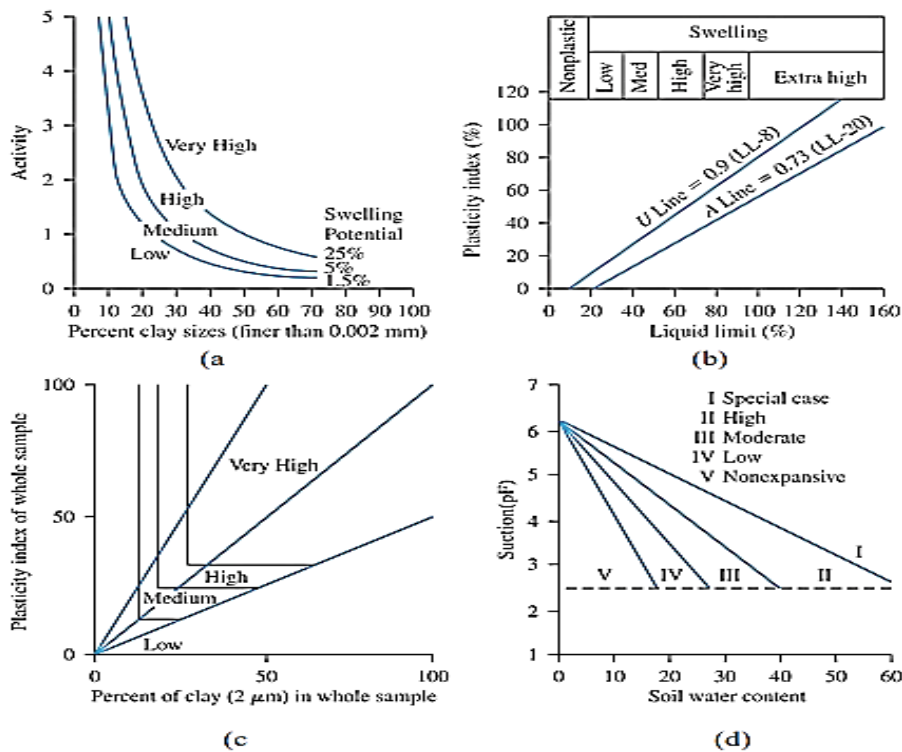


Figure 2. Commonly used criteria for determining swelling potential[13]

5. Treatment of Expansive soil

There are plenty of amendments and treatments to improve these soils and make them suitable for such engineering projects, and soil stabilization technology has been developed in recent decades[10]. Mechanical and chemical techniques are methods usually used to stabilize the expansive soil. Mechanical methods such as surcharge loading,

compaction control, and pre-wetting. Chemical additions, such as lime and cement, chlorides, fly ash, salts, potassium compounds, sulfonated oils, enzymes, ammonium chlorides and polymers, these additives act as a binder that alter soil structure and restrict swelling. Stabilization is a technique used to modify expansive soils in order to make them appropriate for construction purposes. The different

types of stabilizers can be categorized into three groups[10]: The stabilizers used can be categorized into three groups: (a) traditional stabilizers such as lime and cement, (b) by-product stabilizers including fly ash, quarry dust, phosphor-gypsum, and slag, and (c) nontraditional stabilizers including sulfonated oils, potassium compounds, polymers, enzymes, and ammonium chlorides. The disposal of substantial amounts of industrial byproducts as fill material on disposal sites located near industry not only necessitates significant space but also gives rise to several geo-environmental issues. Various companies and researchers have made efforts to utilize them in large quantities at appropriate locations. Utilizing these byproducts for stabilizing expansive soil is a viable approach.

6. Polymer Treatment

The term "polymer" is derived from the Greek word "poly" which means many, and "mer," meaning units or pieces. A polymer is a macromolecule consisting of repetitive structural units connected by covalent connections. Polymers are produced by connecting monomeric components together through a process known as polymerization[16]. In this process, the double bonds between the atoms in the monomers are broken and

new bonds are formed between adjacent atoms, resulting in the formation of long chain molecules as in figure (3). The bonding within the polymer chain is characterized by strong covalent bonds. Nevertheless, the intermolecular bonding between chains is far less strong, specifically of the Van der Waals type. The elongated and pliable chains can be organized in a completely haphazard manner, resulting in an amorphous polymer, or in a structured sequence, creating crystalline areas within the polymer. The distinctive properties of a particular polymer are determined by factors such as the chain length, the level of crystallinity, and the degree of cross-linking between the chains [17].

Polymers can be categorized into two groups, namely thermoplastic and thermosetting, based on their distinct thermal processing behavior. Thermosetting polymers undergo a permanent change in their form when exposed to heat and cannot be softened again by further heating. On the other hand, thermoplastics can be softened and fused together through moderate heating, and then regain their hardness upon cooling. This heating and cooling process can be repeated multiple times without significantly altering the thermoplastic properties[18]

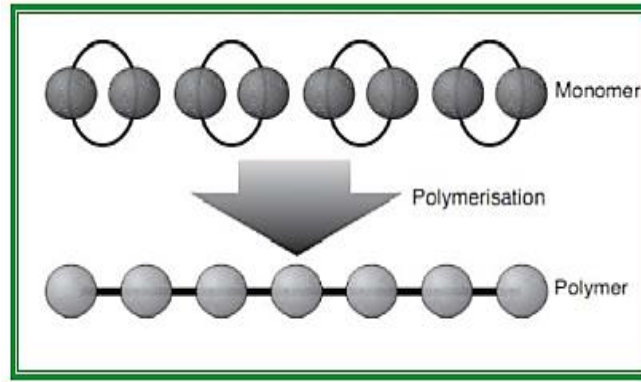


Figure 3. Polymer chain

The precise formulation of polymers utilized in stabilization is usually concealed, with just the brand name being published. Researchers conducted experiments to evaluate several polymers for the purpose of soil stabilization, including those that are currently available in the market. (and the other not). Natural polymer and synthesized polymer are the two common polymers available to stabilize soils[19] Synthesized polymers are the most commercially available polymers.

6.1. Advantages:

The advantages of using polymers as stated by[20] are as following:

1. Polymers reduce Atterberg limit, swell potential, swell pressure, and hydraulic conductivity ,and increase unconfined compressive strength.
2. Polymers do not necessitate a curing period, unlike lime and fly ash.

6.2. Disadvantages:

They can be summarized as follows [19]:

1. The efficacy of commercially available polymer treatment is currently uncertain.

2. Leaching and degradation problems of natural polymers.
3. Typically, the price of polymer is greater than that of lime.

6.3 Classification of Polymers

There are multiple methods of to classify polymers based on some considerations[21].

A- Based on the origin of Source:

There are three sub categories according to this type of classification.

- 1- **Natural polymers:** Polymers found in nature, such as cellulose, proteins, , rubber and resins.
- 2- **Semi-synthetic polymers:** Refer to polymers that are created by chemically modifying naturally occurring polymers in order to change their physical properties. Examples of semi-synthetic polymers include silicones.
- 3- **Synthetic polymers:** They are fibers that are produced in the laboratory through the polymerization of basic chemical components.

4- , such as, polyethylene, polystyrene, synthetic rubber, Nylon, PVC etc.

defined as polymers that are made up of a single continuous chain of repeat units. In these polymers, monomers are joined together to form a long, straight chain. These chains don't have side chains like polyester, nylon, polyathene, or PVC. Furthermore, their molecules exhibit a high density and tensile strength due to their tight packing, as shown in Figure (4).

B- Based on structure of polymers: There are three different types based on the structure of the polymers.

1-Linear polymers on Structure: Linear polymers are

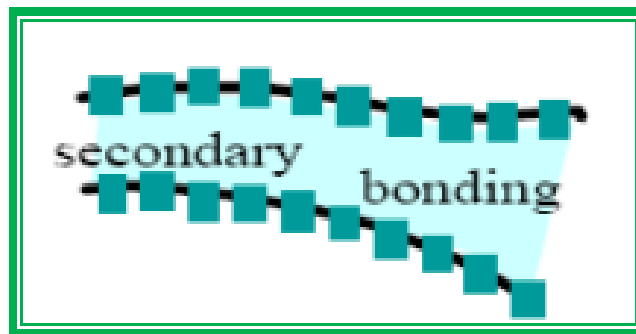


Figure 4. The structure of linear polymer

2- Branched chain polymers: A polymer that contains side chains of repeating units attached to the main chain of repeating units. Their structure consists of a linear main chain with various attached subsidiary chains. The

uneven packing of their molecules results in poor density, tensile strength, and melting point, as exemplified by substances like polypropylene and glycogen, as depicted in the Figure(5)

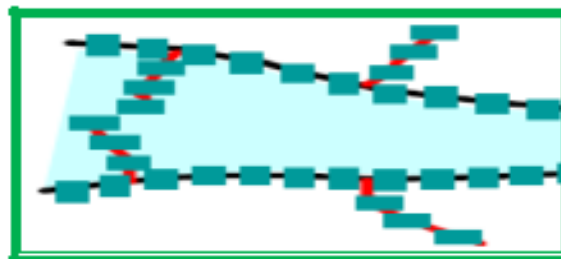


Figure 5. The structure of branched chain polymer

3- Cross linked(Network polymers): Polymers can exist in two forms: as linear chains connected by covalent bonds, or as cross-linked polymers with interconnections between chains in three dimensions. Cross-linked polymers have

a rigid and brittle structure, making them resistant to dissolution in solvents. However, they can absorb solvents like rubber and resins. . These polymers are shown in Figure (6):

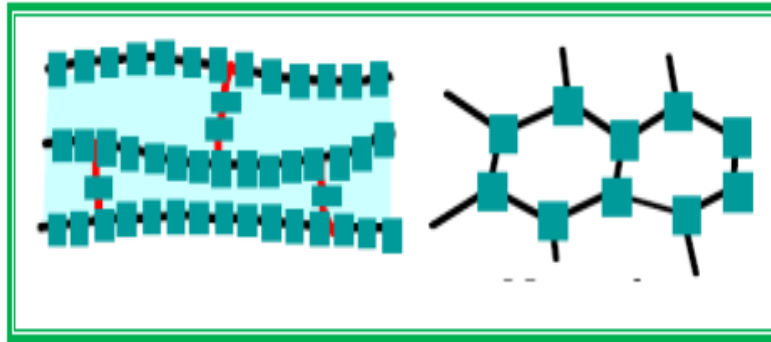


Figure 6. structure of cross linked polymer

C- **Based on Molecular Forces :** Mechanical properties, such as (tensile strength, toughness, and elasticity) are determined by intermolecular forces, called vander-Waals forces and hydrogen bonding. According to basis of these forces[21] they are classified as:

- 1- **Elastomers:** These substances are solid materials that resemble rubber and possess elastic characteristics. The chains in these elastomeric polymers are bound by the least strong intermolecular forces. The polymer can be stretched due to these weak binding forces. Several crosslinks are inserted inside the chains, aiding the polymer in reverting back to its initial state once the force is removed, similar to rubber.
- 2- **Fibers:** Fibers are solid materials that have the ability to form threads and exhibit a high level of tensile strength .The strong intermolecular forces, such as hydrogen bonding, are responsible for these features. The presence of these powerful forces also results in the dense arrangement of chains, so giving rise to a crystalline structure. examples are polyamides, polyesters, etc.

3- Thermoplastic polymers: These polymers have intermolecular forces that are between those found in elastomers and fibers. These substances are polymers that exhibit thermoplastic behavior, meaning they may be rendered pliable through heating and regain their rigidity upon cooling. At the molecular level, increasing the temperature weakens secondary bonding forces, allowing nearby chains to move more easily when subjected to stress. Furthermore, thermoplastics exhibit a high degree of softness and ductility. This characteristic is observed in the majority of linear polymers, as well as in those with flexible chains and branching structures. The thermoplastics that are commercially available are :

- Polyvinyl Chloride (PVC) and Polystyrene
- Polymethyl methacrylate
- Polyethylene
- polypropylene

4-Thermosetting polymers:

Thermosetting polymers undergo a softening process at first heating and then solidify permanently upon cooling. They do not undergo any

change in texture when heated again. Therefore, they are not capable of being molded or reshaped through additional heating, cannot be recycled, do not undergo melting, and may be used at higher temperatures compared to thermoplastics. Additionally, they exhibit greater chemical inertness. In addition, thermoset polymers exhibit greater hardness, strength, and brittleness compared to thermoplastics.

D- Based on Polymerization Mode:

On the basis of the mode of polymerization polymers can also be classified into two sub groups:

- 1- **Addition polymers:** Addition polymers are created by repeatedly adding monomer molecules that have double or triple bonds. These polymers are formed by adding monomers without removing any byproducts. Examples of addition polymers include the formation of polythene from ethene and polypropene from propene. Homopolymers are addition polymers that are generated from the polymerization of a single monomeric species.
- 2- **Condensation polymers:** Polymers are created through the combination of two monomers, achieved by eliminating small components such as water, alcohol, or NH₃.

E- Based On types of Monomers:

- 1- **Homopolyme:** A polymer having a single type of repeat unit ,such as polystyrene.
- 2- **Hetropolymer (Copolymer):** If a polymer is made up from two

different monomers ,it is called copolymer for example , styrene rubber.

6.4. *Previouse Studies of Polymer Treatment*

Hasan et al ., 2017 performed a study on the utilization of Polyacrylamide (PAM), Polyethylene high density (PEHD), and Polymethacrylate (PMA) for the purpose of soil remediation. The test findings demonstrated that the incorporation of PAM, PEHD, and PMA polymers into expansive soil resulted in a decrease in liquid limit (LL), plasticity index (PI), specific gravity (Gs), free swell %, swelling pressure, rebound index (Cr), and optimum moisture content .Furthermore, there was a rise in the plastic limit , unconfined compression strength , especially with extended curing time, compression index (Cc), and California Bearing Ratio (CBR). The inclusion of PAM and PMA polymers increases the maximum dry density (MDD), while the presence of PEHD polymer slightly reduces the maximum dry density (MDD). The swelling potential decreased by 76.7%, 87.2%, and 71.7% as the levels of PAM, PEHD, and PMA climbed to 5%, 12%, and 7% respectively. The test results indicated that the polymers successfully alleviate the difficulties presented by expanding soils. In addition, the addition of PAM, PEHD, and PMA at concentrations of 5%, 12%, and 7% respectively, leads to a 53% rise in UCS for PAM, a 53.7% increase for PEHD, and a 52.8% increase for PMA. The inclusion of equivalent amounts of PAM, PEHD, and PMA polymers led to a corresponding rise in CBR value by

66.7%, 74.8%, and 72.8% respectively [22].

Shafiqu et al., 2018 demonstrated that the addition of polymethacrylate polymer (PMA) to expansive soil was found to decrease several soil properties, such as Atterberg limits (liquid limit (LL), plastic limit (PL) and plasticity index (PI)), free swell percentage, rebound index (Cr), and optimum moisture content (OMC). In addition, it resulted in a rise in the plastic limit (PL), unconfined compression strength (UCS), compression index (Cc), and California Bearing Ratio (CBR). These alterations were noted when examining the impacts of extending the cure period. Furthermore, the incorporation of PMA polymers results in an augmentation of

the maximum dry density (MDD). As the PMA level grew to 7%, the swelling potential decreased by 71.7%. In the same manner, the inclusion of 7% PMA led to a significant 52.8% enhancement in UCS. Furthermore, the incorporation of equal amounts of PMA polymer led to a significant 72.8% enhancement in the CBR value [23].

Khadka et al., 2020 tested two types of geopolymer synthesized from aluminum silicate sources, fly ash and metakaolin at 9% and variable Al/Si/Na molar ratio to assess their efficiency in stabilizing the swelling behavior of high sulfate expansive soils, the results showed a decrease in the swelling percentage, the performance of fly ash was higher than metakaolin [24] as shown in Figure (7)

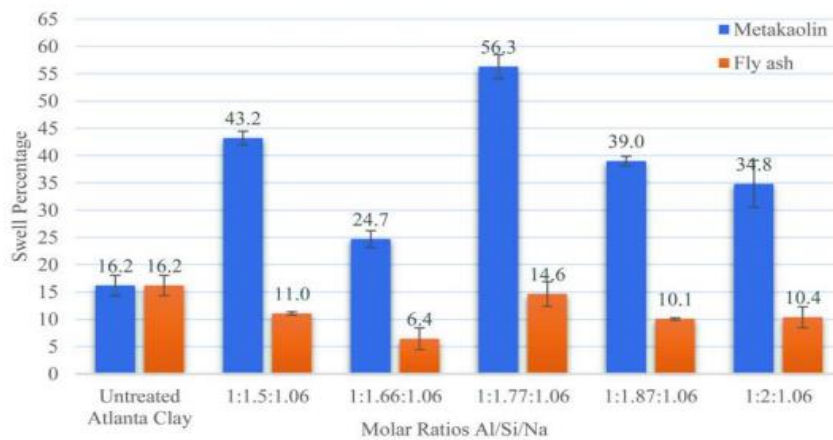


Figure 7. Swell percentages with 9% FA and MK geopolymer at various Al/Si/Na molar ratios [24]

Al-Jeznawi et al., 2021 examined the impact of including Polypropylene polymer (PP) on the characteristics of the prepared expansive soil. The experiment involved applying five distinct percentages (0.4%, 0.8%, 1.2%, 2%, and 4%) of the PP polymer to the natural soil sample. Additionally, two different curing durations

(3 days and 18 days) were taken into account. The incorporation of 0.4% and 0.8% PP polymer resulted in an increase in the liquid limit, plasticity index, swelling potential, maximum dry density, and unconfined compressive strength. Furthermore, these properties continued to rise with the passage of time during the

curing process, namely after 3 and 18 days. The swelling potential of the treated soil samples significantly decreased from 19.2% (of the original soil) to 1.01% (for the original soil mixed with 4% PP polymer and left to cure for 18 days)[25].

7. Biopolymers

They are polymers created from living creatures, such as plants and microbes; provide an alternative to petroleum-based polymers, which have traditionally been the primary source of polymers. Renewable sources are the main origins of

biopolymers. The majority of biopolymers possess the characteristic of being biodegradable, indicating their ability to break down into carbon dioxide, methane, water, inorganic chemicals, or biomass through the enzymatic activity of microorganisms [26]. Biopolymers are anticipated to have the potential to replace 30-90% of petroleum-based polymers, although now representing a minor portion of the polymer market [27]. Mechanical properties for select biopolymers often considered for bio composite matrices showed in table(4).

Table 4. Mechanical properties of biopolymers [26], [28] ,[28].

Biopolymer	Tensile strength (MPa)	Tensile modulus (MPa)	Elongation at break (%)
Poly lactic acid (PLA)	21-60	350-3800	2.5-60
Polyhydroxybutyrate (PHB)	24-40	1700-4000	5-9
Polyhydroxybutyrate-cohydroxyvalerate(PHBV)	25	1000	25
soy protein concentrate (SPC)	50	2000	12
Cellulose acetate	30-40(flexural strength)	1000-2000	-
Starch	5-6	130-850	31-44

Biopolymers possess the capacity to mitigate carbon emissions and diminish the levels of CO₂ in the atmosphere. The reason for this is that the carbon dioxide (CO₂) emitted during the degradation of these products may be absorbed again by crops cultivated to replace them, resulting in a process that is nearly carbon neutral [29]. The selection of a biopolymer for construction is influenced by factors such as mechanical properties, water absorption, photodegradation stability, availability, compatibility, and cost. Polylactic acid (PLA) and Polyhydroxyalkoanate (PHA) are the primary biopolymers in terms of production and utilization, however their main applications are limited to short-term use[31]. Only

starch-based biopolymers can be created without the need for advanced biotechnology, such as advanced fermentation procedures or microbiological approaches. Biodegradable polymers, such as PLA, cellulose esters (cellulose acetate), starch plasti, and aliphatic polyester-copolyesters, are all hydrophilic. Although the initial focus of commercialization has been on short-term applications for biopolymers, current efforts in research and development are aimed toward enhancing the long-lasting properties of these polymers[30].

7.1. Classification of biopolymers

Biopolymers can be classified depending on several scales. Traditionally, three types of

biopolymers can be identified based on their origin. into natural, synthetic and microbial biopolymers, as illustrated in figure(8).

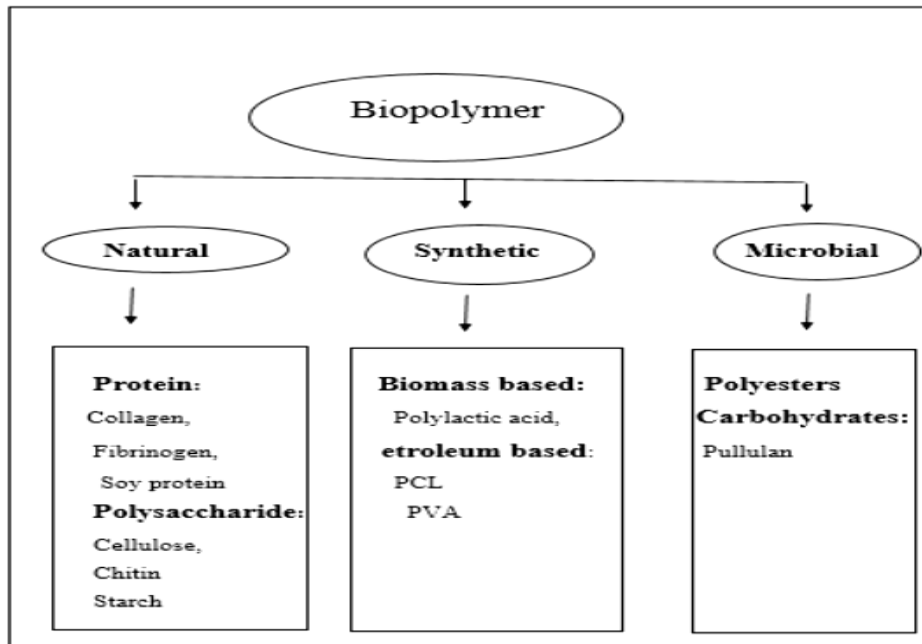


Figure 8. PCL: polycaprolactone, PVA: Polyvinyl alcohol [31]

They can be found in three basic form[28]

1. **Powder form** can be incorporated into cement or mixed with water to make concrete. Examples of substances include chitin, chitosan, starch, and other.

2. **Liquid state:** biopolymers that are typically mixed with water to produce concrete such as rubber, avelós, Araucária, diutan, welan, xanthan, gelan, gutta-percha, guar, and more .

3. **Fiber form:** Biopolymers that have undergone the process of bio polymerization and will enhance the tensile strength of the concrete. Some examples of natural fibers are curauá, coconut, sisal, Spanish broom, hemp, juta, kenaf, and pineapple.

Biopolymers can be classified based on their degradability. Specifically, we can categorize them into two main families: biodegradable and non-biodegradable. Additionally, they can be further classified

as either biobased or non-bio-based. Furthermore, these substances can be categorized based on their polymer backbone, which includes polyesters, polysaccharides, polycarbonates, polyamides, and vinyl polymers. Three classes can be classified based on the type of monomers: polysaccharide, protein, and nucleic acid. Biopolymers can be classified based on their heat sensitivity into three categories: elastomers, thermoplastics, and thermosets. Biopolymers can be classified into various categories, with each group being divided into multiple subclasses. The diagram below displays all of these classes.

7.2. Previous Studies of Biopolymer Treatment:

Taytak et al., 2012 [32] conducted the impact of xanthan gum and chitosan on the engineering properties of soils. Two

different biopolymers were utilized in different quantities for this purpose. Compaction and hydraulic conductivity studies were conducted to examine this phenomenon. The natural kaolin and bentonite samples were used as representative clayey soils. The findings suggest that including xanthan gum and chitosan biopolymers increases the maximum dry density of the bentonite-kaolin-sand mixes. However, the presence of chitosan biopolymer greatly amplifies the action. The presence of chitosan and xanthan gum biopolymers decreases the rate at which water may flow through the combinations of kaolin and sand. However, over time, the permeability decreases as a result of the degradation produced by biopolymers[32].

Latif et al., 2017 [17] performed an experiment to assess the effectiveness of(xanthan gum) biopolymer on twotypes of clay: (1)sodium bentonite clay, which is mostly composed of montmorillonite minerals that are recognized for their ability to swell; and (2)white kaolinite clay. The results of the UCS test indicated that the optimal amounts of xanthan gum to achieve stability were 1% for bentonite and 1.5% for kaolinite. Typically, when stabilized specimens were tested, it was observed that greater amounts of additives and longer periods of curing led to higher shear-strength values in UCS tests and direct shear tests. Additionally, these conditions resulted in increased stiffness (indicating less compression) and higher yield stress values in 1D consolidation tests. The mechanical properties of the stabilized specimens exhibited the most notable enhancement during the early 28 days of the curing process. From day 28 to

day 90, there were only insignificant alterations seen in the parameters. After only 7 days of curing, significant improvements in the engineering properties were seen for both stabilized clays, with no use of additives. The statistics presented clearly show that xanthan gum has a high ability to effectively stabilize difficult clay soils[17].

Cabalar et al., 2018 [33] performed an examination on the engineering characteristics of a low-plasticity clay improved with xanthan gum biopolymer. The samples were produced by mixing clay with different proportions of xanthan gum biopolymer by weight (0%, 0.5%, 1.0%, 1.5%, 2.0%, and 3.0%). Afterwards, the specimens were assessed following different intervals of curing (0, 7, 28, and 56 days). The test findings showed that the strength of the clay samples increased in relation to both the biopolymer content and the time of the curing procedure. The test results indicated that the permeability of the samples treated with xanthan gum biopolymer decreased, while the compression index and swelling percentage values were higher compared to the untreated samples[33].

Joga et al., 2019 [34] investigated the impact of Xanthan Gum (XG) as a potential treatment for expanding soil. The test results revealed that the addition of biopolymer content leads to a decrease in the Maximum Dry Density (MDD) of the soil and an increase in the Optimum Water Content (OMC). The unconfined compressive strength (UCS) of the soil is quadrupled when 1% xanthan gum is

added, and the soil is cured for 28 days. The compressibility of the soil is reduced by 65% after a 28-day curing period. The addition of xanthan gum content enhances the shear characteristics of treated soil. Scanning electron microscopy (SEM) was

used to analyze the tested materials. The analysis showed that the soil fabric had white lumps and the gaps in the soil structure were filled with cementitious gel shown in figure (9(a,b))[34].

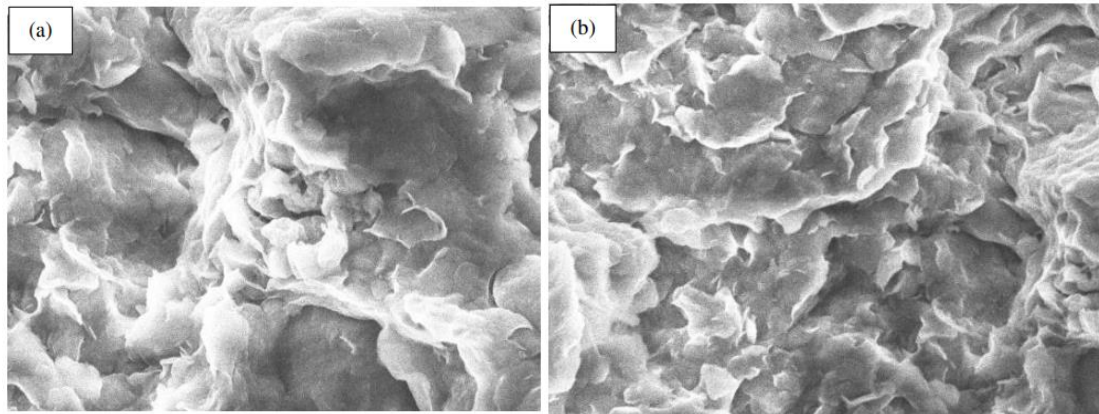


Figure 9.SEM analysis of treated soil with 1% XG at various curing periods: (a) 7 days; (b) 28 days after [34]

Chang et al., 2020 [35] conducted a study on the impact of adding biopolymers, specifically an anionic xanthan gum biopolymer and a cationic ϵ -polylysine biopolymer, to improve the geotechnical engineering characteristics of soft coastal soil. The use of xanthan gum alters the Atterberg limits, shear strength, and compressive strength through the process of interparticle bonding and the creation of a thick and sticky hydrogel. Nevertheless, the presence of xanthan gum prolongs the process of consolidation and enhances the compressibility of soils. Although the application of ϵ -polylysine did not have an impact on the compressive strength, it demonstrates promise in causing the aggregation of soil particles when they are in a suspended form[35].

Soldo et al., 2020 [36] conducted a study on the impact of incorporating biopolymers into Residual Piedmont soil

to assess their effectiveness in enhancing soil strength. This study examined five biopolymer types: Xanthan Gum, Beta 1,3/1,6 Glucan, Guar Gum, Chitosan, and Alginate. The comprehensive experimental results demonstrated a positive correlation between the content of biopolymers and soil strength, as well as between curing time and soil strength. Nevertheless, it has been demonstrated that the soil's strength remains relatively stable once a specific concentration of biopolymer and curing period has been reached. Moreover, it has been noted that the specimens treated with biopolymers exhibited enhanced resistance to the effects of external conditions[36].

Mendonça et al.,2021 [37] revealed the impact of the xanthan gum biopolymer in enhancing soil characteristics. The test findings have demonstrated that the application of xanthan gum in soil

treatment leads to the partial filling of the empty spaces in the soil and the creation of extra connections between the soil particles. This, in turn, reduces the permeability coefficient and enhances the mechanical characteristics of the soil[37].

Weng et al ., 2021 [38] examined the impact of combining xanthan gum and polypropylene fiber on the characteristics of red clay obtained from a foundation pit located at a depth of 3 m–5 m in Kunming, Yunnan, China. The test findings indicated that the composition and duration of curing of xanthan gum had a substantial impact on the unconfined compressive strength of red clay. The best ratio for strength enhancement, ranging from 41.52 kPa to 64.73 kPa, was found to be 1.5% xanthan gum concentration when compared to untreated soil. Conversely, the red clay that was treated with xanthan gum exhibited an increase in strength. The soil treated with 2.0% xanthan gum-polypropylene fibers had strengths that were 1.9–2.41 times more than that of red clay and 1.12–1.47 times greater than that of clay treated with 1.5% xanthan gum[38].

Hamza et al., 2022 [39] showed the effectiveness of xanthan gum (XG) biopolymer as an environmentally friendly construction solution for addressing issues with unstable subgrade soil. The soil treated with different proportions, taking into account the extended duration of aging. The results indicated a marginal reduction in the highest density of the treated soil as the optimal moisture content increased.

When the XG content was at an ideal level of 1.5%, the strength parameters, such as the UCS-value, wet and unsoaked CBR, experienced a considerable rise of 1.8–9 orders of magnitude. This transformation turned the weak subgrade into a high-quality subgrade suitable for pavement construction. Furthermore, the compression and rebound indices reduced by 83% and 82% respectively, while the swell percentage and pressure were cut by 79% and 86% correspondingly[39].

8. Conclusions

This review demonstrated the introduction of biopolymer as an environmentally acceptable material for improving clayey expansive soil, as well as the extent to which it may be made commercially available. As for biopolymer materials used (Guar Gum ,Chitosa , Xanthan Gum,..ect). Studies have shown the extent of the response of the engineering properties of these materials, as we saw a noticeable improvement represented by reducing swelling potential, increasing unconfined compressive strength , and reducing the Atterberg Limits, in addition to reducing Compressibility of soils . Taking into account that most studies were conducted in scientific laboratories, it is recommended in the future to use biopolymer materials to improve soils and in situ for farther research

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