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A Review on Biopolymers as an Eco-Friendly and Sustainable Solution for Soil Stabilization

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Abstract. The impact of traditional stabilization method on the soil is now a major concern for all the researchers. The amount of carbon dioxide emitted by cementitious materials in the soil has made global researchers to think about materials quite sustainable that are eco-friendly too. While considering sustainability there has been ample number of choices for soil stabilization. However, all the sustainable materials are not considered as eco-friendly and delivers an adverse effect to the soil. To overcome these adverse effects, bio products are introduced into the soil which has a promising future in the field of sustainable geotechnics. In this review paper, the center of attraction is biopolymer, an eco-friendly material which is derived from sources like plants, animals and microorganisms. There are enormous materials which are extracted from nature, a very few are commonly used in the field of soil engineering. Though biopolymers, such as Xanthan and guar gum have shown immense increase in the strength of soil when added in different proportions. When compared to traditional material with biopolymer, a very less amount is require to attain the comparable strength. Biopolymer has proved itself to be versatile in the strength property but was found to be lacking behind when brought in contact of water. Biopolymers for stabilization are suitable for cohesive and cohesion-less soil with higher strength, which makes it the best option in place of traditional technique.

Keywords: Soil Stabilization; Biopolymers; Strength Improvement.

1 Introduction

Since the dawn of human civilization, the technical discipline of geotechnical engineering has been practiced, particularly with regard to the handling and application of soil (or earth) in construction. Geotechnical engineering entailed stabilizing and enhancing the soil. The methods and supplies for doing this, like stabilizing the soil and combining it with conventional concrete binders, have indeed been applied to designed soil treatments. Approaches that are environmentally advantageous alternatives are essential. Possibilities, such as geotextiles, chemical monomers, geopolymers, microbial induction, and natural polymers, are being intensively investigated. Due to its widespread application as a realistic soil remediation agent, cement generates a substantial amount of global warming gases [14]. Subsequently, a variety of techniques and materials have been employed to enhance the characteristics of soils. Portland cement emerged as the foremost used substance for building and treating soil, especially following the Industrial Revolution. [26, 35]. In the building sector, Portland cement is a substance that offers a number of well-known advantages, including affordability, toughness, workability, and durability. The manufacture and use of cement, however, are linked to some environmental concerns. The emissions associated with the usage of cement as one of main contributors of CO2 emissions in the global level, accounting for roughly 8% of total CO2 emissions worldwide [14, 35].

The top priorities of soil application and betterment, also referred to as designed soil, are to enhance a particular soil's engineering characteristics, like its internal resistance, hydraulic gradient, and resilience under repetition drying and wetting circumstances, in addition to increasing environmental rejuvenation. Physical augmentation and chemical modification have historically been the two basic methods for producing customized soil. Physical enhancement is the method of improving the soil's material characteristics, such as deformation, permeability, exterior loading (such as overlay), consolidation, and perhaps other methods. When soil is treated chemically, interior chemical mechanisms such hydrolysis or cementitious reactions, which artificially link soil particles occurs together. One example of this is the usage of calcium silicate hydrate (C-S-H) [43].

For every ton of Portland cement produced, 0.55 tons of CO2 are released during the calcination of calcium carbonate and released into the atmosphere. Additionally, as calcination requires heat at a temperature of up to 1450°C, roughly 0.4 tons of CO2 are released during the manufacturing of 1000 Kilogram of cement as a consequence of the burning of carbon fuel. Every time a ton of cement is manufactured, 0.95 tons of CO2 are released into the atmosphere [31]. Although the usage of cement contributes to numerous ecosystem problems, the building sector also uses about 40% of all the energy worldwide [4].

When it comes to soil engineering, biological approaches are currently being actively researched as a substitute to such traditional methods of soil treatment and enhancement. Particularly for soil treatment and enhancement, biopolymers have been presented as a novel kind of building binder [14]. Ordinary Portland cement and geopolymers have stronger fortifying effects than biopolymer techniques, but both utilize massive quantities of binders (10% to 50% of the soil's mass in binders, on average) nevertheless, biopolymers need 0.5% to 1.0% of the soil's weight in binders to reach strength levels comparable to those produced by intensive cement mixing. 0.5% biopolymer combinations are required to attain strengths that are comparable to or even greater compared to those for 10% Ordinary portland cement-soil combinations [11]. This study offers an overview of biopolymer in geotechnical engineering in response.

2 Biopolymers A Sustainable Approach

Polynucleotides (such as Ribonucleic acid and Deoxyribonucleic acid), Carbohydrates and proteins (fatty acid molecules), that have already been historically among the most common types frequently used in diverse engineering procedures, three primary typical types of key biopolymers that are taken into consideration [8, 36, 47]. Organic polymers called biopolymers are created by living things. They are made up of monomeric pieces that are joined together to form larger forms. In fact, the utilization of biopolymers is not a completely new innovation in geotechnical engineering. In a broad sense, organic polymers like natural bitumen, straw, and sticky rice are also biopolymers and have been employed by ancient civilizations. As a binding agent, sticky rice mortar was utilized in ancient Chinese culture. Actinidia chinensis cane liquid, lime, loess, and riverbed sediment were combined with glutinous rice broth to form a paste that has adequate resistance, high stiffness, and water-resistant properties [8, 50].

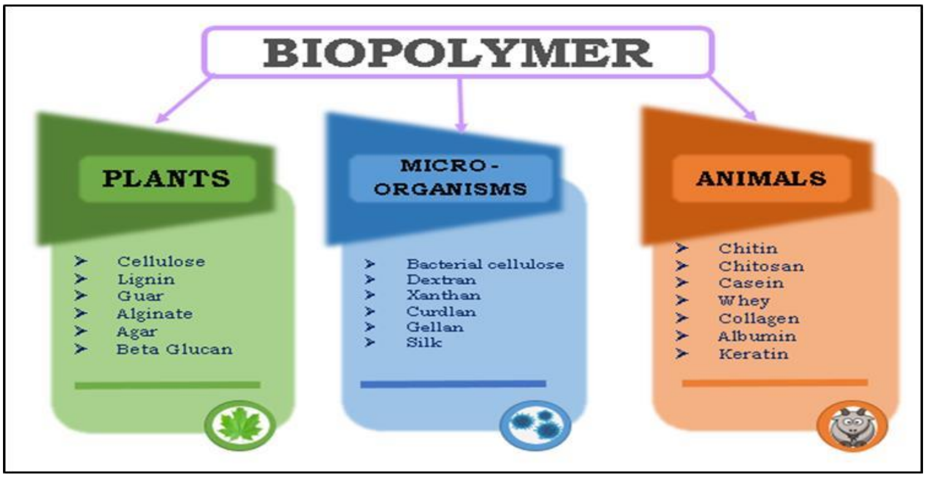

Fig. 1. Classification of Biopolymer [25].

Biopolymers can be classified into groups as shown in Figure 1, a list of biopolymers, organized by the production of source, that are mostly used for soil improvement. Plant-based biopolymers are produced using vegetation and agricultural waste. Biopolymers are generally made of plant-based materials, the majority of which are polysaccharides, and are used in geotechnics. Among the compounds in this category are cellulose, lignin, guar, alginate, agar, and beta-glucan. Microorganism-based biopolymers include xanthan gum, gellan gum, and dextran, which are made from bacteria through fermentation methods. Biopolymers originated from animals are those that are made from animal products. Waste crustacean shells, such as shrimp shells, are used to make chitin and chitosan, while milk and dairy products are used to make protein-based biopolymers [25].

3 Types Of Biopolymers

XANTHAN GUM: Due to its properties as a hydrocolloid rheology modifier, xanthan gum, a polysaccharide produced by aerobic degradation of sucrose by the bacterial species Xanthomonas campestris, is frequently employed as a food ingredient [6, 20]. It is a D-uronic acid, D-mannose, pyruvylated mannose, 6-0-acetyl D-mannose, and 1, 4-linked glucan anionic polysaccharide [45]. Two tri-saccharide components pair with each glucose element in the chemical structure to form a linear chain 1, 4-linked -D glucose backbone. Between two D-mannose components, a D-glucuronic acid component makes up the other side chain [10, 45]. The Figure 2 shows the chemical structure of xanthan gum where the aerobic fermentation of Xanthomonas campestris on glucose and has a cellulose backbone with two mannose and one glucuronic acid side chains [20].

GUAR GUM: The leguminous plant seeds endosperms are processed to produce the non-ionic polysaccharide known as guar gum [21]. They work well as a soil supplement since they are totally soluble in water and non-toxic. The primary component of guar gum is a linear chain of high molecular weight galactomannans (1 → 4)-linked β-D-mannopyranosyl units with (1 → 6)-linked α-D-galactopyranosyl residues as side chains as shown in Figure 3 [34].

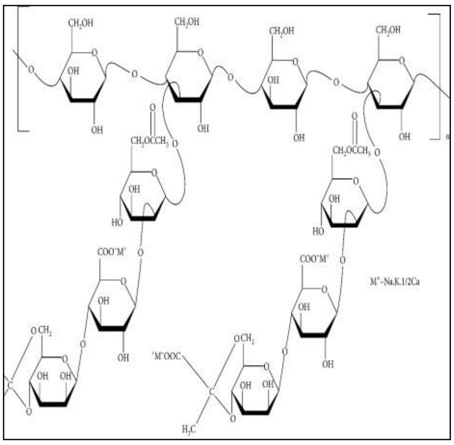

Fig. 2. Xanthan Gum [20]

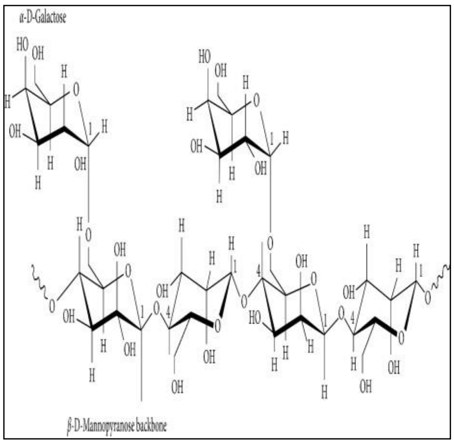

Fig. 3. Guar Gum [34]

CHITOSAN: The degraded form of chitin, known as chitosan (P-(1, 4)-2-amino-2-deoxy-D-glucose), is present in exoskeletons of crustaceans and cell walls of fungus. Typically, alkali sodium hydroxide treatment is used to remove it. Numerous applications have been made use for this hydrophilic biopolymer. Nourishment, material science, health sciences, microbiological, immunological, in addition to other sectors including farming, effluents, and degrading goods have all used and researched chitosan. Chitosan is a bio renewable, biocompatible, biodegradable, and bio functional biopolymer [37, 42, 49]. Chitin is a copolymer of α-(1→4) glucosamine (C6H11O4N) n, with varying numbers of N-acetyl groups, while chitosan is its deacetylated derivative as presented in Figure 4 [32].

BETA-GLUCAN: Biopolymers called beta-glucans are made of D-glucose monomers that are joined by glycosidic linkages [3]. Natural sources of glucan include plant material, cereal, and the cellular membranes of bacterial, yeast, and fungus, as well as other forms [15]. A polymer found in layers of the embryo of legumes crops called β-glucan as shown in Figure 5 it is composed of straight glucose chains with β-(1 → 3) and β-(1 → 4) connections. The β-glucan found in yeast and fungus, in contrast, was made up of (1 → 3) connections and (1 → 6) connected branches [44].

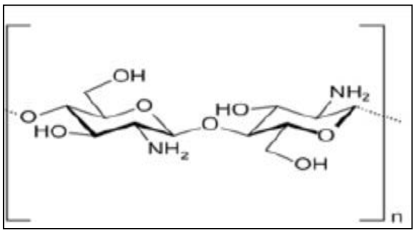

Fig. 4. Chitosan [32]

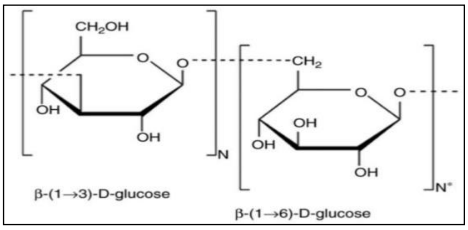

Fig. 5. Beta - Glucan [44]

AGAR GUM: Rhodophyceae are the source of the polysaccharide known as agar gum, which is made up of linked galactose molecules [26]. The rheological characteristics of agar gum make it effective as a thickening, stabilizer, and emulsifier. Agar gum also has a thermo mechanical emulsification ability that allows it to form solid solutions once reduced down to ambient degree after becoming dispersed in hot water. [33]. Agar refers to gelling polysaccharides as presented in the Figure 6 having an alternating 1,3-linked β -D-galactose and 1,4-linked 3,6-anhydro- α -L-galactose disaccharide called agarobiose or neo-agarobiose repeating unit as its primary backbone structure [30].

GELLAN GUM: A high molecular weight polymer called gellan gum is produced by microorganisms called Sphingomonas elodea (formerly known as Pseudomonas elodea) [27]. Agar gum is typically replaced with gellan gum because of its many similarities to that substance, particularly its thermogelation capabilities [24, 46]. A tetra-saccharide repeating unit of two β -D-glucose, one β -D-glucuronic acid, and one α -L-rhamnose residue is connected together in this structure as given in Figure 7 [22].

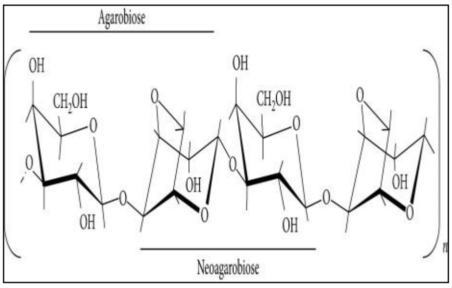

Fig. 6. Agar Gum [30]

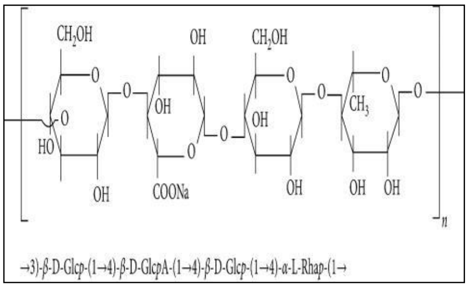

Fig. 7.Gellan Gum [22]

4 Biopolymers Used In Soil

Chitosan has been demonstrated to have the ability to decontaminate groundwater that contains pollutants like copper (II) (Cu^{2+}) and phosphorus in geotechnical and geoenvironmental situations (P-) [16, 41]. Practical applications for chitosan-coated layer sand particles in purifiers for groundwater clean-up [49] and can reduce the hydrostatic conductivity of sandy soils sediments to produce an appropriate plugging effect [28]. **β -Glucan** mix when compared to the strength of a 10% cement mix (2170 kPa), a modest amount of 0.25 percent of beta- glucan (i.e., ratio of mass to soil) in soil, produces a compressive strength of 2650 kPa, whereas 0.5 percent beta-glucan mixing results in soil strength of up to 4310 kPa [11]. According to geotechnical analysis, beta-glucan improves soil's shear stiffness (G) and Atterberg limit values while having little to no impact on the soil's constrained modulus (M) [12, 13].

Agar Gum without harming the environment, significantly increases the strength of sand (particularly cohesiveness) [29]. Researchers recently tried to use agar gum to increase soil strength. They found that using 3 percent (to soil mass) thermally treated agar gum increased soil's unconfined compressive strength up to 10 MPa when the soil was dried [10]. **Gellan Gum** due to its strong strengthening effect, gellan gum has a lot of potential for use in engineered soil [19]. According to a recent study, clayey soil containing 3% gellan gum has a maximum unconfined compressive strength of 12.6 MPa [10].

Xanthan Gum for the purpose of pore filling in geotechnical engineering has been introduced. This reduces the hydraulic conductivity of silty sand [6]. Additionally, raising the liquid limit will improve the soil's undrained shear strength [38]. Another current study identified the possibility for xanthan gum to be used as a soil strengthener and demonstrated that the substance preferentially creates hard xanthan gum-clayey soil matrices through hydrogen bonding [9]. **Guar Gum** helps building work in arid regions, attempts have been made to employ viscosity-controlled guar gum with additives such acrylamide, ammonium persulfate, and formaldehyde as injected grout for sand stabilization [23]. Guar gum can be used to prevent cracking at shallow depths by stabilizing expansive soils, such as desert sand, on slopes [1, 40]. Additionally, guar gum slurry has reportedly been used to make vertical barrier-walls (such as cut-off walls) [17, 48].

4.1 Biopolymer Soil Interactions

To increase the overall effectiveness and dependability of soils treated with biopolymers, different types of biopolymers and/or workable application techniques might be combined. Because most biopolymers are highly sensitive to water, it is imperative to find ways to make biopolymer-treated soils more successful in it. This will increase the soils' dependability for ground stabilization and improvement. A number of approaches had been researched and also developed to address these problem, such as the usage of biopolymers with thermo-gelation capabilities. As was previously mentioned, biopolymers with such thermo-gelation capabilities include gellan gum and agar gum. When the gel is cooled to room temperature, the biopolymers begin to stiffen and becomes highly soluble in water at a temperature of around 85 ˚ to 90 ˚ C. Even when exposed to water, these thermo-gelating biopolymers maintain a significant amount of strength [24, 46].

Table 1. Soil biopolymer interaction.

Soil	Biopolymer	Curing time	Observations	Remark
Sand	Xanthan Gum, Guar Gum	-	copper metal absorption capacity to 85.6 and 60.7%, and reduce leachability to 10.3 and 22.8%	**[18]**
Sand with silt	Xanthan Gum, Guar Gum	1-10 weeks	Cohesion of the sand was enhanced by 447 kN/m2 and 218 kN/m2, and unconfined compressive strength value raised by 270 kPa and 790 kPa	**[2]**
Sand	Xanthan Gum	1, 3, 7,14 & 28 days	Hydraulic Conductivity value was decreased	**[7]**
Sand bentonite mixture	Xanthan gum	-	Increase in permeability value	**[5]**
Kaolinite soil	Xanthan Gum, Guar Gum	-	Liquid limit values of soil treated was 185.9%. With the addition of salts decreased the liquid limit of soil to 120.8% and 130%,	**[38,39]**

Cross-linking of biopolymers might provide an effective method of stabilizing soil in addition to current methods. Cross-linking is a technique, which is used to considerably enhance a material's properties by adding a component that promotes interactions between various polymer chains, increasing their overall strength. Cross-linking is widely employed when sulphur is introduced to rubber polymers, a process known as vulcanization, which significantly increases the rubber's strength and stiffness.

5 Conclusions

A number of cement alternatives, various ideas, such as using biopolymers directly inside the soil profile, have been put forth, as well as the development of green cement. Recent research has demonstrated that biopolymers can enhance the soils. They have a number of benefits in these applications, including being environmentally friendly and efficient at shallow concentrations. According to numerous studies, the strengthening brought on by biopolymer treatment is greatest in the presence of fines, particularly clay particles.

Various investigations have demonstrated that in the presence of fines, particularly clay particles, maximizes the strengthening brought on by biopolymer treatment. Biopolymers, as an alternative to cement, have a significant capability to lower the emissions of carbon dioxide. Additionally, a number of biopolymers demonstrate the ability to support vegetative development and stabilize, which can be used as defence against threats to environmental conservation as well as the preservation of farmland and anti-desertification.

The ability to manufacture it ex-situ and apply in-situ with a greater level of quality control makes the biopolymer implementation superior to that of other biological soil approaches. Additionally, biopolymers may be mass manufactured in a commercial setting and react within the soil particles pretty quickly immediately after mixing, making them useful for quick or temporary support.

Limitations: Despite having many advantages of using biopolymers, there are currently numerous problems that must be fixed, such as their susceptibility to water, high cost, and potential biological degradation. Overall, the utilization of biopolymers in soil engineering seems to have a bright forthcoming given the large range of accessible biopolymers, their ability to be modified easily, and the multiple favorable qualities that they exhibit

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