APPLICATION OF XANTHAN GUM BIOPOLYMER FOR TREATMENT OF EXPANSIVE SOIL: A REVIEW

Gaurav chandravanshi[1], S.K Jain[2]

[1]*Post graduation Student, Department of civil Engineering, MITS Gwalior, Madhya Pradesh, India*
[2]*Professor, Department of Civil Engineering, MITS Gwalior, Madhya Pradesh, India*

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Abstract – In this paper, the collaboration in the fields of geotechnical engineering and biotechnology in an environment friendly approach to soil treatment and preservation are discussed. Traditional soil stabilizer such as lime, cement, fly ash and other chemicals are being utilized to suppress the problematic behavior of expansive soils for centuries. Among them, lime and cement are commonly preferred additives. However, these additives have adverse effects on the environment.

For this reason, biological approaches have been studied in the recent years to be used as an alternative to reduce the traditional way of stabilization of soil. This paper reviews the work carried out on the stabilization of different varieties of soil using biopolymer, also it shows that biopolymers have strong potential to replace the conventional soil binder as a soil treatment material within the context of environment friendly construction and development.

Key Words: Biopolymer, Xanthan gum, Expansive soil, Soil Treatment, Sustainable Development

1. INTRODUCTION

The main purpose of soil stabilization and ground improvement activities is to alter the geotechnical engineering properties of soil to improve its design parameters, such as compressive strength, hydraulic conductivity, durability, and erosion resistance (Chu et al.2009; Sherwood 1993) [18]. There are two widely used ground improvement and soil stabilization practices. The first is mechanical improvement whereby the properties of the soil are reinforced via physical process, such as compaction, drainage, external loading, and consolidation. The second is to enhance the soil by applying chemical additives that bind the soil particles together by the way of a chemical reaction, such as cement hydration or pozzolanic reactions. The most widely used material for chemical ground improvement is cement; however, cement has several environment unfriendly properties such as greenhouse gas emissions, which limit its use as a sustainable material (Chang and Cho 2012) [19]. Biological approaches, such as microbe injection and by product precipitation, have been studied in recent years as an alternative to reduce the use of high CO_2 emitting soil binders in geotechnical engineering practices. In particular the use of biopolymers and biological induced polymers has been studied as prospective construction binders. Biopolymers are reasonable and environment friendly in light of the fact that they are by and largely created from anthropogenic horticulture crops. At present, the biopolymers are mainly being used in the applications of plants growth or vegetable plant cover. Their main function is for soil erosion control and prevention of slope failure (Karol 2003) [26]. Many biopolymers have been exploited as a soil stabilizer to improve the mechanical behaviour of different types of soil. A Few of such biopolymers are explained below.

1.1 Xanthan Gum

The biopolymer xanthan gum is a natural polysaccharide produced by the microorganism xanthomonas campestris. It is a natural anionic polysaccharide composed of D – glucuronic acid, D – mannose, pyruvoylated mannose, 6 – 0 – acetyl D – mannose. It has a natural rheology modification tendency of fluid. The well-known characteristic of XG are pseudo – plasticity and high shear stability even at low concentration (Chen and Sheppard, 1980) [21]. Moreover, it has several desirable properties including pH stability, storage stability and ionic salt compatibility (Jansson et al (1975)) [20]. Because of these properties, XG has found a wide range of applications in cosmetics, oil, paper, paint, pharmaceutical industries, food and textile industries as gelling, thickening or suspending agent and as a flocculant or for viscosity control. The chemical structure of xanthan gum is shown below.

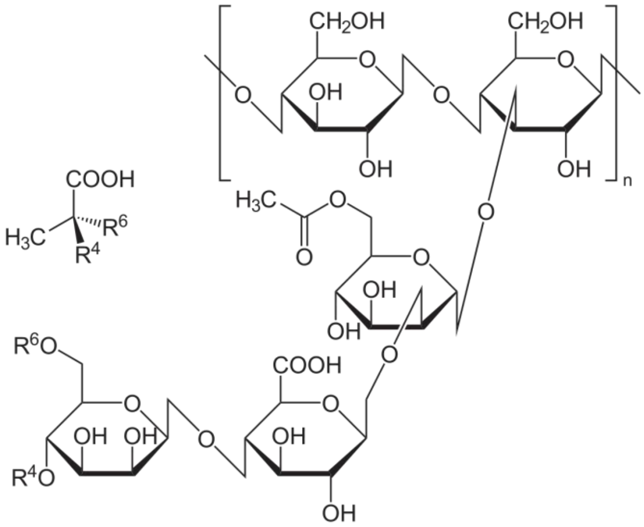

Figure. Chemical structure of Xanthan Gum

1.2 Beta-glucan

Beta-glucan are biopolymers that consists of D- glucose monomers that are linked by glycosidic bonds (Bacic et al.2009) [22]. It is naturally found in the cellulose of plants, the bran of cereal grain, and the cell walls of various organisms, such as yeast, fungi, mushrooms, and bacteria (Cui 2001) [23]. Beta-glucan have been used in cosmetic products, super plasticizers, and as water reducing agents (Chang and Cho 2014) [19].

1.3 Agar Gum

Agar Gum is a polysaccharide that is composed of linked galactose molecules, and is extracted from rhodophyceae (Ivanov and Chu 2008) [24]. Agar gum has rheological properties that make it useful as a thickener, stabilizer and emulsifier. One important characteristics of agar gum is its thermogelation property, which means that it is easily dissolved at temperatures close to that of boiling water and forms a stiff hard gel when cooled back to room temperature of 20°C (Duckworth and Yaphe 1971) [25].

2. RESEARCH FINDINGS

Based on literature review and research planning, the outcome of the researches are as follows-

Al – Khanbashi and Abdalla (2006) determined the effects of water borne polymers on sandy soil stabilization with styrene-acrylic, a co-polymer and vinyl-acrylic co-polymer-based emulsions. Hydraulic conductivity, compressive strength and scanning electron microscope (SEM) measurement were also discussed. To measure the properties; a flexible membrane liquid apparatus was used, and unconfined compression test and microscopic examination were conducted. The soil used in the experiment was classified as poorly graded sand (SP) based on the USCS classification. According to the modified Proctor test procedure (ASTM 1557), for polymer content of 5%, the optimum moisture content was 6% and the maximum dry density was 1.67M/m^3. From permaemeter tests, the hydraulic conductivity was decreased. When the polymer content exceeded 3% by weight and reached a minimum of 5% polymer content. All the polymers increased the strength and the stiffness of the sand, and the vinyl acyclic produced the best effect in terms of increasing the strength and modulus values.[1]

Cabalar and Canakci (2011)

In this experimental study, the authors investigated the effect of Xanthan gum on the behavior of sand using a direct shear testing apparatus. The test was conducted with various proportion of Xanthan gum (1%, 3% and 5%) by weight on water demand at different curing times 7, 26, and 50 days under three different vertical stresses (111, 139, and 167kPa). The rate of loading was selected as 1mm/min. In case of untreated specimen, the maximum direct shear strength were found to be 45, 86, and 101kPa respectively.

Addition of 1% Xanthan gum maximum reduced the maximum direct shear stress values under all vertical stress (111, 139, 167kPa). But as the xanthan gum content has increased (i.e. 3% and 5%), the direct shear stress values also increased significantly. That was a general trend followed in this experimental analysis. The impact of curing was not significant within the studied range of time. The similar trend was observed at 26 days and 50 days of dry curing.

The authors concluded that these results would open up the way for a whole new era of study linking biology with geotechnical engineering including dynamic and static deformation properties. [2]

Naeini et. al. (2012) focused on the unconfined compressive strength of clayey soils stabilized with different dosages of water borne polymer, and described laboratory experiments for testing the effects of the curing time, polymer content, and plasticity index. Different dosages of polymers (2, 3, 4, and 5%) were added to three fine grained clayey samples with different plasticity indexes. The soils were then compacted under optimum water content and maximum dry density conditions (ASTM D-155 7). Strength with different curing time (2, 4, 6, 8, and 14 days) were determined by unconfined compression tests according to ASTM D2 166. The unconfined compressive strength increased rapidly during first 8 days then remain constant for 14 days. The unconfined compressive strength increased with polymer content, and reached a maximum at polymer content of 4%. The plasticity index is another important parameter that affects unconfined compressive strength. Based on the test results, a higher polymer content could affect the stress, strain behavior of soil samples by changing them from brittle to ductile behavior due to an increase in plasticity index. For application in roadways, a 4% polymer content and 8 day curing time recommended for soil stabilization. [3]

Ilhan Chang et al (2014) studied the engineering performance and efficiency of Xanthan gum biopolymer in the stabilization of different types of soil (sand, natural soil, red soil, and clay). Compressive strength measurement and SEM analysis were performed to investigate the macro and micro – interaction of soil-biopolymer mixture. The authors found that compressive strength of clay at 28 days was increased 6-fold at 1% XG substitution (i.e. from 440kPa – 2540kPa) while with same, the natural soil and Red yellow soil showed compressive strength to be 3680kPa and 4940kPa respectively. The authors also found that 1% XG – soil mixture results in higher compressive strength than 10% cement treated soil. At last the author concluded that strengthening effect of xanthan gum was found to be dependent on four factors; type of soil, hydration level (moisture content), xanthan gum content and mixing method.[4]

Ilhan Chang et al (2015) studied the effect of XG, gellan gum and OPC on Korean residual soil (KRS). KRS soil consists of quartz (8.4%), kaolinite (45.8%), halloysite (22.7%), illite (14.8%) and geo-ethite (8.3%). The authors found that UCS value of untreated KRS was close to 1 MPa while that of 1% gellan gum treated soil was 2.5MPa.

In case of 1% XG substitution in KRS soil, the authors found that compressive strength reaches to 6.31MPa which is more than 2.3 times higher than that of soil mixed with 10% of OPC i.e. 2.65MPa. Also, the authors established that according to the design criteria for earthen structure (BS EN 1996-3), 1% XG treated soil having strength equal to 6.3 MPa qualify to be used for low risk building which states that minimum strength of wall element should exceed 5.2 MPa.[5]

Ilhan Chang et al (2015) conducted experimental studies to obtain a better understanding of the effects of biopolymer treatment on soil revitalization and prevention of desertification.

In this study, the authors stabilized Korean red-yellow soil having particle composition (sand=30%, silt=68%, and clay=2%), Atterberg limit values (LL=43%, PL=32%) with two biopolymers namely xanthan gum and beta-glucan.

In the experimental analysis, the authors conducted laboratory precipitation and stream erosion simulation approach for short term severe and long term severe precipitation to evaluate the erosion resistance of soil, effect of biopolymer on the cultivation of vegetation and soil moisture retention against evaporation.

The author analyzed that erosion tendency of biopolymer treated soil remained relatively low (i.e. below 1%) regardless of soil-moisture increment. Also, biopolymers treatment promoted both initial seed germination up to 300% and overall sprout growth. The soil moisture retention efficiency with biopolymer treatment was found to be 9% higher than untreated natural soil at room temperature.

At last, the authors concluded that biopolymer treatment can be a promising supplement or alternative countermeasure for various aspects of soil preservation and desertification prevention including improvement of soil erosion resistance, retention of soil moisture and promotion of cultivation.[6]

Nima latifi et al (2016) employed both macro as well as micro-scale testing approach for the stabilization of organic peat with xanthan gum as stabilizing agent. In the macro scale testing, compressive as well as shear strength characteristics of both untreated and stabilized peat were evaluated. The tests were carried out in different proportions by weight of soil i.e. 0.5%, 1%, 1.5%, 2%, and 2.5%. The study revealed that as the curing time increased both the cohesion and internal friction angle of stabilized specimens increased significantly. Cohesion for untreated soil (0.5kPa) which increased to 33kPa for stabilized peat at 28-day curing. Similarly, ϕ increased from 23° to 29° after 28-day curing. In UCS test compressive strength increased about six times from 13kPa for untreated specimen to 83kPa for stabilized specimen after 28 days of dry curing. The authors also concluded that the strength enhancement occurs significantly in first 28 days of curing and after that the enhancement in strength becomes insignificant.

In the micro-structural analysis, the author conducted FESEM, N_2BET and PSA test on untreated and treated peat-specimens. Using FESEM, the changes in soil structure can be evaluated to examine the morphology of cementing material. The authors finding suggested as curing time increased dispersed, discontinuous noticeable voids in untreated peat sample were vanished and new cementious products forming a new gel like white lumps reduced the voids and strengthen the interaction between xanthan gum and soil. The specific surface area of the specimen was also reduced through N_2BET analysis. N_2BET analysis is used to examine the porosity of treated particles. At last, the authors conducted PSA analysis through CILAS machine and found that xanthan gum stabilization causes a reduction in amount of clay sized particles i.e. from 37% to 11% after 28days of curing which is associated with increase in silt size particle from 63% to 89% after 28 days of curing. PSA analysis is used to assess the resulting size of treated particles (i.e. information of agglomeration). [7]

A.F Cabalar et al (2017) studied the effect of xanthan gum on sand for improving its engineering properties. He employed various mix ratio (0%, 0.5%, and 1% and1.5%) of biopolymer by weight of sand and conducted various lab test viz. UCS test, permeability test, odometer test and triaxial shear test at varying curing times(0, 3, 7, 14, and 28) days.

The testing result shows that higher xanthan gum concentration produced lower permeability values. For e.g. permeability of untreated sand was 8.46×10^{-5}m/s and at 1.5%XG substitution, the values reaches to 2.84×10^{-11}m/s which was about a million-fold.

Secondly the authors found that with the increase in XG content in sand and with increasing curing time the unconfined compressive strength also increases rapidly, about more than twice while it decreased the compressibility by about a half. The void ratio sharply declined with increased XG content. Shear strength parameter i.e. c and ϕ values for untreated sand (c=0, ϕ=30°) and the other values the observed were (c=32kPa & ϕ=28° for 0.5%XG), (c=58kPa & ϕ=30° for 1%XG) and (c=91kPa & ϕ=29° for 1.5%XG). [8]

Mohsin U Qureshi et al (2017) In this study, the authors investigated the engineering properties of dune sand obtained from Al-Sharia desert in Oman and improved it by using xanthan gum biopolymer. In the experimental analysis, the authors conducted compaction test, UCS test, triaxial test and slake durability test. The specimen for each test prepared by mixing xanthan gum biopolymer with sand at various proportion (1%, 2%, 3% and 5%) by weight The outcome of the results showed that that the maximum dry density increased up to 1% XG substitution and then decreased while OMC decreased up to 1% XG substitution and then increased up to 3% XG substitution and again decreased.

Consistency limits (LL, PL) also increased with the increase in biopolymer content. LL for 1%, 2%, 3% and 5% XG treated sand were evaluated as 18.9%, 23.6%, 28% and 35.6%. In fact, plasticity index too enhanced with increased Xanthan gum content.

The average UCS of untreated AS sand was found to be 15kPa while with xanthan gum substitution of 1%,2%,3%and 5%, the UCS values were found out to be 1076kPa, 1700kPa, 753kPa and 1024kPa respectively which showed that UCS values increased up to 2% of XG treatment and then decreased.

Inter particle cohesion of XG treated sand was found out to be 36kPa, 334kPa, 343kPa, and 223kPa at 1%, 2%, 3%and 5%XG substitution respectively while the angle internal friction increased up to 2% and then decreased. At last, the durability of treated sand was found by conducting slake durability test which showed that with increase in xanthan gum content up to 3% slake durability index also increased in proportion but with higher percentage of substitution it decreases.[9]

Lavanya and Kumar (2017) stabilized red mud (a fine grained industrial waste or bauxite residue) with two different biopolymer namely Xanthan gum and Guar gum (0.5%, 1%, 2% substitution). The test conducted were light compaction test, unconfined compression test, split tensile strength test and specific gravity test. They found that on increasing biopolymer content in soil specific gravity decreased. The authors also observed that maximum values were obtained at optimum dosage of 1%. On addition of biopolymers, moisture content values increased while maximum dry density decreased. Authors conducted UCS test for different curing period (0, 3 and 7 days) and found that with increasing curing period strength also enhanced. UCS values are low at high dosages (2%) and high at 1% dosages. Based on the findings, the authors suggested that red mud can be used as alternative material in place of conventionally used gravel materials. [10]

Ali –Firat cabalar et al (**2018**) In this study, the authors studied the geotechnical properties of low plasticity clay which were improved by Xanthan gum biopolymer. Clay was quarried from Gaziantep University Campus, Turkey. Its liquid limit, plastic limit and specific gravity were 38.5, 23.5 and 2.76 respectively. Most of the clayey soil are often problematic in nature in various geotechnical engineering application due to high compressibility; low strength and high swelling. So, the authors conducted a series of laboratory tests i.e. unconfined compression test, direct shear test, permeability test, swelling and shrinkage test to examine the improved behavior of clay treated with biopolymer.

After conducting the laboratory tests, the authors found that with increase in Xanthan gum content, there was a substantial decrease on dry density but an increase in optimum moisture content.

Unconfined compressive strength of clay not only increased with biopolymer content increment but also with curing time. For clay with 0.5%XG content substitution, compressive strength values were measured to 383kPa, 471kPa, 613kPa, and 669kPa at 0, 7, 28, and 56 days respectively.

The cohesion values increased with xanthan gum content and curing time increment but internal friction angle decreased with increase in xanthan gum content. While a clear relation between internal friction angle and curing time was not observed.

Also, the test results showed that coefficient of permeability (K) decreased sharply from 6.5×10^{-7}cm/s (clay only) to 1.2×10^{-7}cm/s by addition of 1% XG. So, higher content of XG produced lower permeability.

At last, the linear shrinkage values changed slightly with addition of Xanthan gum biopolymer although the swelling percentage changed substantially with same amount of additive.

At last, the authors suggested that Xanthan gum biopolymer could be used at specific content (1-3%) to stabilize the low plasticity clay. [11]

Suresh Prasad and Ritesh Das (2019) stabilized the expansive soil using xanthan gum biopolymer. Soil was collected from Rourkela Steel Plant, India. Soil collected contains sand (17%), silt (47%), clay (36%) and was classified to be as high plastic silt (CH). Liquid limit, plastic limit, specific gravity, OMC, MDD and differential free swell index were evaluated and were estimated to be 86%, 25%, 2.75, 21%, 16.70 KN/m^3 and 217% respectively. After experimentation of laboratory test, the author found out that liquid limit got increased up to 0.8% and then decreased. While plastic limit value continuously increased up to 1%of XG content. Also, with increasing biopolymer content, the authors asserted that Shrinkage limit values have increased and linear shrinkage values decreased.

In light compaction, MDD value decreased from 16.09KN/m^3 to 15.91KN/m^3 while OMC increased slightly from 21% to 22.1% whereas in Heavy compaction, MDD value increased marginally from 17.43KN/m^3 to 17.61%KN/m^3 with increasing XG concentration from 0 to 1%. Furthermore, with increased additive level and curing time, yielded increased compressive strength and stiffness value. 1% XG addition results about 93% increase in compressive strength while swelling pressure was reduced by 54%. Compressibility of treated soil increased marginally but hydraulic conductivity decreased sharply. At last Microscopic examination through SEM images confirmed the particle agglomeration and formation of gel-like cementitious materials. [12]

Joga and Varaprasad (2019) studied the improvement in stiffness and strength of xanthan gum treated clays. The clayey soil used in the study has a liquid limit of 91%, P.L of 39%, specific gravity 2.56 and FSI of approximately 160%. The authors conducted both macro and micro-structural experiments which comprises of standard proctor test, UCS test, direct shear test, 1-D consolidation tests, and SEM analysis. The tests were conducted with different concentration of XG biopolymer (0, 0.5%, 1%, 1.5%, and 2.5%) and different curing time (0, 7, 28 and 90 days). The authors observed that MDD reduced from 16kPa to 13.7kPa while OMC slightly increased from 32% to 37.3% as the substitution of XG increased from 0 to 2.5%. Also, , the authors found that UCS value increased about four times after 28 days of curing from untreated clay(447kPa) to stabilized soil (1504kPa) at 1% XG substitution.

Both cohesion and angle of internal friction increased with increased biopolymer content and curing time. Cohesion value increased five times from (114kPa to 513kPa) after 28 days of curing period for 1% XG biopolymer content. Similarly, ϕ increased from 18.6° to 22.3° after 28 days curing period. Also after 28 days curing period ,compression index decreased by 62.6% compared with untreated soil while swelling index also reduced from (0.44 to 0.16) for same curing period. The authors found in general that stabilized specimen showed most significant changes during initial curing period of 28 days and further there is minor increase during curing period of 28 days to 90 days. The authors recommended the use of xanthan gum as an alternative to traditional soil stabilization methods. [13]

Nair and kannan (2019) evaluated the effects of the behavior of two biopolymers namely Xanthan gum and Guar gum in terms of engineering properties to kutta-nad soil. Kutta nad soil is an important soil group which has low shear strength and high compressibility. The authors conducted the study with different concentration of both biopolymers (0.5%, 1%, 1.5% and 2% by weight) and evaluated their effects on compaction characteristics and compressive strength. The authors found that both the biopolymers showed an increase in compaction characteristics, Xanthan gum was found to be most effective at optimum concentration of 2% while the optimum concentration for Guar gum was 1.5%. Also, with increase in biopolymer concentration, maximum UCS value for was found out to be 90.3KN/m^2 at 2%XG substitution and for guar gum it was 95.1KN/m^2 at 1.5% substitution. Finally, the paper suggested guar gum to be more promising than xanthan gum in stabilization of kutta nad soil. [14]

Sojeong Lee et al (2019) investigated the feasibility of Xanthan gum biopolymer as a soil stabilization material for a road shoulder construction in Sri Lanka. They compared the strengthening effect of Xanthan gum with conventional cement, fly ash and bottom ash blended binders C8F2 (Cement 80%, fly ash 20%); C8F4 (Cement 60%, fly ash 40%); C8F2-B (cement 56%, fly ash 14% and bottom ash 30%) and C6F4-B (Cement 42%, fly ash 28%, bottom ash 30%). They tested for unconfined compressive strength for varying binder content and curing time. The authors found that initially after 3 days of treatment xanthan gum had lower UCS value than other binders but after 28 days of dehydration XG treated soil was remarkably better than others. The authors also mentioned that XG treated soil had higher ductility than cement-based binders treated soil which is another distinctive feature they found. They also found that that 2%XG treatment is optimum condition for stabilized sub bases in road shoulder construction which met design criteria of almost all developed countries. [15]

Soldo and miletic (2019) investigated the effect of Xanthan gum on the engineering properties of soil with different granulometry (sand, silty sand and clay). The authors evaluated the strength of soil by conducting three mechanical tests-unconfined compression test, unconsolidated undrained test and direct shear test. The study was conducted with 1%XG substitution with different granulometry (i.e. sand, silty sand and clay). They found out that compressive strength of Xanthan gum substituted silty sand was significantly higher than that of xanthan gum substituted clay and sand. Compressive strength of silty sand with and without XG substitution was 1.2MPa and 3.35MPa respectively which showed an increase of 180%.Compressive strength of sand with and without XG substitution was 0 and 2.02MPa respectively while in case of clay, compressive strength with and without XG substitution was 0.7MPa and 1MPa respectively which showed an increase of 0.3MPa with respect of plain clay. They also found that in UU test, Xanthan gum amended silty sand and xanthan gum amended clay showed a similar magnitude of maximum deviatoric stress (1.7 MPa in silty sand 1.63 MPa in case of clay) which actually increased by 42% in 5 days of curing in both types of types of soil. At last, they found that in case of direct shear test, the presence of xanthan gum can increase the shear strength of sand and silty sand but its effect on clay was marginal. [16]

Soldo et al (2020) experimentally investigated the biopolymer effect on residual piedmont soil on its mechanical properties extracted from south-east part of United States. In order to achieve that, five different biopolymer types xanthan gum (XG), beta 1, 3/1, 6 glucan (BG), Chitosan (CHI), Alginate (ALG) were used with different biopolymer concentration (1%, 2% and 4%) and under different curing times (5 days and 30days), four mechanical strength tests were performed – unconfined compression test, splitting tensile test (ST), Direct shear test (DS) and unconsolidated undrained test (UU). After conducting the tests, the authors found that curing time increased the strength values measured in UC, ST, and UU test. They also mentioned that size of specimen has important role in achieving maximum strength. The authors also pointed out that high concentration of biopolymer does not guarantee high soil strength which means optimum biopolymer concentration may vary with biopolymer type, soil type and water content. Finally, they concluded that out of five polymers which were used XG, GG and BG showed the most dominant effect on the improvement of soil strength. For the soil used, the optimum biopolymer concentration of XG was close to 2% whereas, the optimum GG concentration was close 1%. In case of BG, authors suggested that further research is needed to provide an estimate for the optimum BG concentration.

Thus, at last authors suggested that XG, GG, and BG showed promising results for soil stabilization and enormous potential for future sustainable engineering. [17]

3. CONCLUSIONS

This review paper summarized the importance of the application of biopolymers in geotechnical engineering and has provided various examples of the applications of the Xanthan Gum biopolymer on different types of soil and examine their effectiveness on the properties of various soils , the study outcomes showed that-

- The strengthening induced by biopolymer treatment is maximized in the presence of fines, especially clay particles.
- The strengthening effect is greatly influenced by four factors; type of soil, hydration level (moisture content), xanthan gum content and mixing method of biopolymer content.
- Biopolymers especially xanthan gum has strong potential to reduce carbon dioxide emissions. Moreover, some biopolymers show functionality to support vegetation growth and stabilization; which can be applied as a countermeasure for farmland preservation anti- desertification and against other threats to environmental conservation.
- Low percentages of about 1-3% of the xanthan gum may be adopted to improve the properties of clayey soil.

- Biopolymers especially xanthan gum and guar gum have the potential to reduce Aeolian erosion and promote vegetation growth vegetation growth arid and semi-arid deserts.
- There is an increase in compressive as well as shear strength of soil specimens in many different soils with increase in curing time.
- Although their benefits are numerous; several challenges related to use of biopolymers remain to be addressed; including sensitivity to water, market cost, and possible biological degradation. Overall given the wide variety of available biopolymer; the flexibility of their modification; and the numerous advantageous properties that they possess, the use of biopolymers in geotechnical engineering appear to have a promising future.

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BIOGRAPHIES

Gaurav Chandravanshi
M.E.- Civil (CTM)
PG Student, MITS Gwalior,
Madhya Pradesh

Dr. S.K. Jain
PdF, Ph.D., M.E.,
Area of Interest: Structural
Dynamics & Earthquake Engg.
Project guide, MITS Gwalior,
Madhya Pradesh