Geotechnical Properties Of β-Glucan Treated High Swelling Clay

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Abstract. Soil stabilization refers to enhancing the properties of a soil for engineering purposes. A holistic approach in selection of materials for soil stabilization is required since certain materials may cause environmental problems such as pollution during manufacturing, interaction with ground water table, soil nutrients, etc. β-glucan, a biopolymer offers a novel alternative and has greater potential for application in soil stabilization, yet only limited research is available. β-Glucans are linear homopolysaccharides composed of D-glucopyranosyl residues linked via a mixture of β -(1 - 3) and β-(1 - 4) linkages. β-glucan has good tensile strength along with good bonding and adsorption characteristics. In addition to structural orientation, molecular weight plays a role in stabilization owing to gel forming potential. Polysaccharides have the tendency to form a film coating. β-glucan was added in quantities of 0.5%, 1%, 1.5%, 2%, 2.5% and 3% to high swelling clay soil. Index and select engineering properties of the treated soil were determined. Rheological properties such as pH and viscosity were also studied. Durability tests, tests on biopolymers such as gel matrix formation and its degradation were conducted. The test specimens were prepared for 0, 7, 14, 28 and 56 days to study the impact and variation of shear strength on treated soils. Scanning Electron Microscopy images revealed the bonding of β-glucan and soil. The treated soils have shown improvement in engineering properties.

Keywords: Soil stabilization, Biopolymer, Engineering Properties.

1 Introduction

With rise in global warming, potential environmental friendly solutions could be harnessed efficiently in various industries. Biopolymers are produced naturally by living organisms and their final disposal need not require any treatment since they are biodegradable. Depending on the natural source, various types of polymers in the form of polysaccharides with different matrices are present [1]. β-glucan is a natural fiber present in oats, yeast, mushrooms, etc. It is a valuable non-starch polysaccharide present in the cell walls of oats, barley, etc. [2]. Biopolymers have the ability to form an interconnected tumesced polymer network. Biopolymers have applications in improving the stability of food items in spread products [3]. They are also used in cosmetics, pharmaceuticals, materials science industries [4]. In textiles, utility of xyloglucan results in strength increment of yarns [5]. Some of the biopolymers are chained with the opposing groups which improve the interfaces of the biopolymers rendering them to be dissolved in water and oil [6]. Molecular weight of a biopolymer is an important factor in rheological properties of β-glucan [2].

Agar biopolymer induced cohesion to cohesionless soil and improved the strength of the soil [7]. Even at low concentrations, xanthan gum, agar, gellan gum have tremendous improvement in strength of the soils. Biopolymers are prone to degradation and one way to improve the durability of them is to offer thermal treatment [8]. Consolidation test revealed that xanthan gum reduced the compression and swell indices of the expansive soils [9]. Utilization of xanthan gum on sandy soil improved cohesion and friction angle but the increase in cohesion was predominant. Xanthan gum increased the stiffness and decreased the hydraulic conductivity of the sand [10]. Xanthan gum soil samples tested after 750 days exhibited a little increment in strength without any degradation [11]. Biopolymers are generally known to increase the plasticity of soil [12]. Galactomannans are not influenced by strength of the ions because they are anionic. Guar gum is durable enough to resist adverse temperature cycles [4]. Literature studies indicate the potential benefits of biopolymers in soil strengthening, permeability, decontamination of soil, etc.

2 Methodology

2.1 Material

Commercially available sodium bentonite was used. The Free Swell Index of the bentonite was found to be 430 %. Sodium bentonite contains montmorillonite and illite mineral groups which cause the soil to swell tremendously. For the bentonite, the liquid limit was found to be 240%. Plasticity index was 174%. Flow and toughness indices were determined as 97.98 and 1.77 respectively.

2.2 Sample preparation

The specimens for unconfined compression test were prepared by wet mixing method owing to their better performance than dry mixing in clayey soils. [13] Water was added to β – glucan powder at its optimum moisture content when tested with sodium bentonite clay. Thus β – glucan solution was obtained and kept sealed for 2 hours. The β – glucan solution was then thoroughly blended with the bentonite and enclosed to prevent loss of moisture.

2.3 pH and viscosity

pH test was performed in accordance with IS: 2720 (Part 26) – 1977 [14]. 30 g of the untreated and treated soil were taken in a 100 ml beaker and 75 ml of water was added. The suspension was stirred for few seconds and pH meter was calibrated using standard buffer solution. Electrodes were washed with distilled water, dried with the help of an ordinary filter paper and then immersed in the soil suspension. Three readings of the pH of the soil suspension were taken with brief stirring in between each reading. For determination of viscosity, a series of standard solutions of polymer was prepared and for each standard solution, the flow time was calculated. Viscosity of the biopolymer was tested using U tube viscometer.

2.4 Gel matrix and dehydration tests:

β – glucan powder of 1.3 grams was poured in a measuring jar followed by addition of water for 0.05 liters. This test was performed to interpret the hydration of β – glucan. Dehydration test involved the exposure of β – glucan to sunlight for 180 days by sealing the top of the measuring jar.

2.5 Liquid and plastic limits

Consistency of a fine grained soil is the physical state in which it exists. It indicates the degree of firmness of a soil. At liquid state, the soil offers no shearing resistance and can flow like a liquid. Liquid and plastic limits were determined as per IS: 2720 (Part 5) -1980 [15]. Using the slope of the flow curve, flow index was calculated. At plastic limit, the soil loses its plasticity and passes to a semi solid state.

2.6 Standard Proctor Test

Standard proctor test was used to identify optimum moisture content and maximum dry density of the high swelling clay. The maximum dry unit weight of the soil depends on water content, amount of compaction, type of soil, method of compaction and use of admixtures. 3 kilograms of air dried samples passing through 4.75 mm sieve was used for compacting the soil. The test was performed in accordance with IS: 2720 (Part 7)-1980 [16]. After four hours of mixing the test was done.

2.7 Unconfined Compressive Strength

A cylindrical soil specimen, of size 38 mm diameter and 76 mm height, is loaded axially by a compressive force until failure takes place. Unconfined compression test has zero confining pressure. The axial or vertical compressive stress is the major principal stress and the other two principal stresses are zero. This test is suitable for saturated clays and was performed as per IS: 2720 (Part 10)-1991 [17].

2.8 Durability test

Durability test was performed for 12 cycles of alternate wetting and drying for the treated and untreated soil specimens. The soil specimens which were prepared as per optimum moisture content were enclosed in a cling film on the sides. The soil specimens were placed in a moist chamber for a week and were then submerged in water for 300 minutes. The weight of the soil specimens and the dimensions were measured. The soil specimens were subjected to 70^{o} C for two days. The measurements were recorded once again. This methodology was repeated for 12 cycles and measurements were noted for changes in volume and weight. IS: 4332 (Part 4) – 1968 procedure was followed in performing this test [18].

2.9 Scanning Electron Microscopy

Specimens from the failure plane of unconfined compressive strength test were studied using the images from scanning electron microscope. Micro structural changes due to potential particle aggregation could be illustrated by SEM.

3 RESULTS AND DISCUSSIONS

3.1 pH and viscosity

The change in pH of the soil on adding β-glucan was negligible. This indicates that the addition of β-glucan does not alter the concentration of hydrogen ions in the soil. Viscosity of the biopolymer did not increase on addition of water. Even when subjected to heating until 90^{o} C, viscosity did not increase due to lack of gel formation. Viscosity of the β-glucan solution resulted in 0.0009 Ns/m^2 which was equal to the viscosity of water. At lesser temperatures, a thermo-reversible gel could be formed for a period of time [19].

3.2 Gel matrix and dehydration tests:

β-glucan did not produce gel instantaneously. After 15 days, the water containing β-glucan powder was marginally viscous. After 45 days, the β-glucan did not deteriorate when it was exposed to atmosphere. The biopolymer solution was transformed into a solid matrix with increase in height of the polymer matrix with increasing number of days. Even after 180 days, degradation did not take place. This test illustrated the stability of β-glucan when subjected to sunlight.

3.3 Atterberg's limits

Liquid and plastic limits increased as the percentages of biopolymer content increased. It rose from 240% for the clayey soil to 440% for 3% β-glucan replacement. Plastic limit and plasticity index showed similar increasing trends for increasing percentages. At 0.5%

and 3% replacement, percentage increase in liquid limit and plasticity index were 8.33%, 4.54% and 83.33%, 37.88 respectively. Variations in the consistency limits were due to specific surface of soil particles. Being a hydrophilic polymer, β-glucan modifies the double layer of the clayey soil. Results of liquid and plastic limits are presented in Table 1.

Table 1. Liquid and plastic limits for different percentages.

Percentages	0%	0.5%	1%	1.5%	2%	2.5%	3%
Liquid limit (%)	240	260	344	360	396	430	442
Plastic limit (%)	66	69	72	78	84	89	91
Plasticity index (%)	174	191	272	282	316	341	351
% increase in liquid limit	-	8.33	45.83	50	65	79.17	83.33
% increase in plastic limit	-	4.54	9.09	18.18	27.27	34.85	37.88
Flow index	97.98	105.42	113.57	117.52	129.14	134.17	137.11
Toughness index	1.77	1.81	2.39	2.4	2.45	2.54	2.56

Flow index denotes the rate at which the soil loses its shear strength with increasing water content. As the water content increases, the flow curves tend to be steeper and the shear strength of the soil decreases. Toughness index is a measure of shear strength of the soil at plastic limit. Toughness index of the treated soil increased as the percentage of β-glucan increased. 40% increase in toughness index was observed from 1% illustrating the fact that soil's resistance against shear stresses were improved.

3.4 Maximum Dry Density and Optimum Moisture Content

Increase in biopolymer content led to increase in Optimum Moisture Content (OMC) and it remained fairly constant on further addition. β-glucan, even though a hydrophilic biopolymer, did not form gel immediately and the increase in water content did not result in higher optimum moisture content. The Maximum Dry Density (MDD) increases by 1 kN/m^3 at 0.5% and it did not rise or decline further for subsequent percentages. Compaction results are presented in Fig. 1.

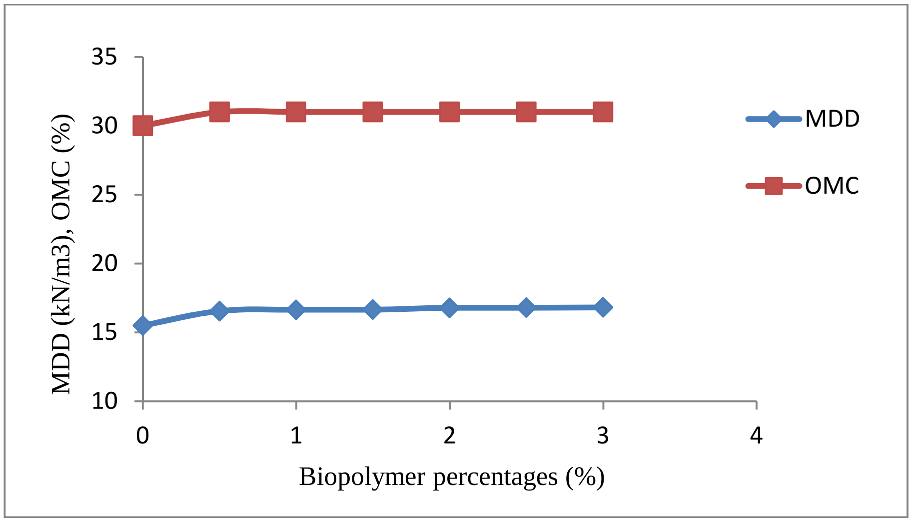

Fig. 1. Optimum Moisture Content and Maximum Dry Density

MDD values of treated soil were higher than the MDD of untreated soil at all biopolymer contents investigated even though the increase was marginal. Fiber formation by β-glucan resists the compactive efforts and deter the particles from moving closer to each other. This limits the increase in dry density though the treated soil fiber becomes stiffer on β-glucan addition. This is evidenced by the increase in toughness index as seen from the Table 1. Increase of optimum water content is a result of the hydrophilic property of the biopolymer used in the study. [20,21,22]

3.5 Unconfined Compressive Strength

Unconfined compressive strength tests were conducted for samples cured on 0, 7, 14, 28, 56 days for 0%, 0.5%, 1%, 1.5%, 2%, 2.5% and 3% addition of β-glucan to the clayey soil. The results indicate that 2% addition of biopolymer by replacing the soil was the most optimum in increasing the unconfined strength of the soil. 50% increase in strength was observed for the treated soil at 2% on comparison with untreated soil for 28 days. The results are shown in Fig. 2.

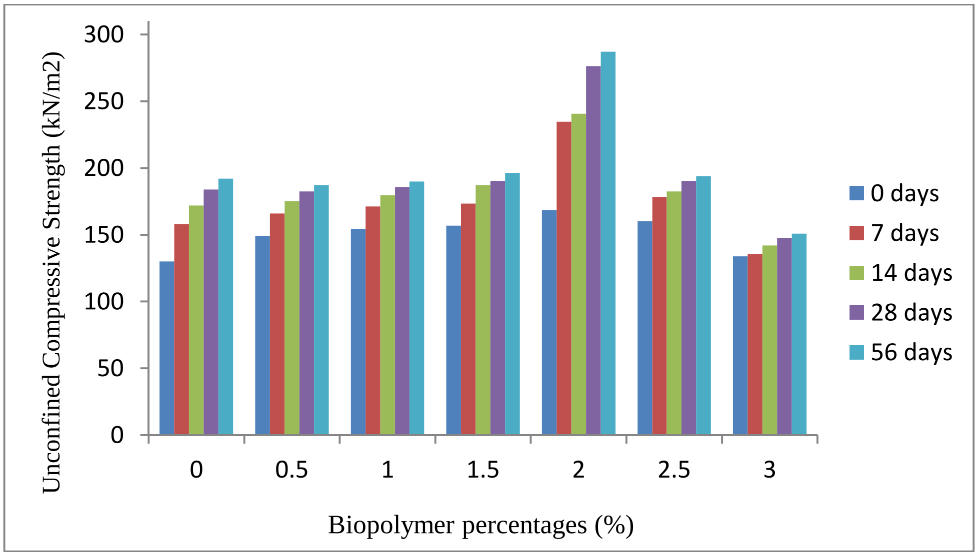

Fig. 2. Unconfined Compressive Strength for 0 to 56 days

After 28 days, the percentage increase in strength was marginal. The increase in unconfined compressive strength was due to the hydrogen bonding of β-glucan with the soil. The development of connection linkages between the soil and biopolymer increased as the number of days increased. Fig. 3. shows the failure modes of unconfined compressive strength test.

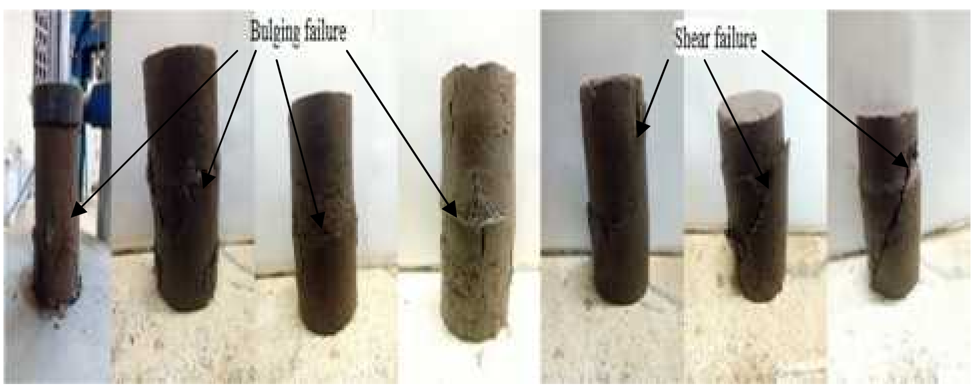

Fig. 3. Unconfined Compressive Strength failure specimens

β - glucans which possess good tensile strength have potential applications in controlling the cracking and tensile failure of many earth structures [22]. For stabilization of slopes, improvement in cohesion increases the shear strength of the soil. 2% of β - glucan shall be best for increasing the strength of the soil which has applications in improving pavement subgrade, stability of slopes, etc.

3.6 Durability test:

There were no signs of appreciable variation in weight and volume of the soil specimens after 12 cycles of alternate wetting and drying. Not more than 3% weight changes were observed which could be attributed to the stability of the biopolymer and the bonding of soil-biopolymer linkages. The marginal increase in weight may be due to hydration of β-glucan. Durability specimens have been shown in Fig. 4.

Fig. 4. Durability test specimens

3.7 Scanning Electron Microscopy

Fig. 5. shows the 28 days microstructure of soil and soil - β-glucan blend.

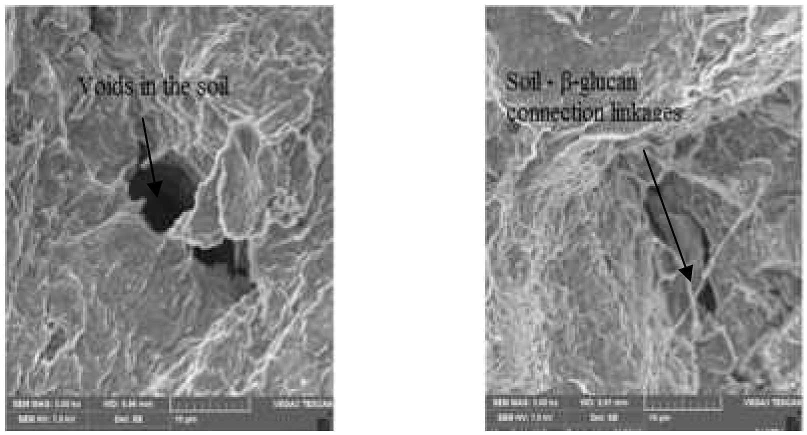

Fig. 5. 28 days SEM images of soil and soil- β-glucan (2%)

Scanning Electron Microscopy images indicate that the soil voids have been filled by the β-glucan and a dense soil - β-glucan network has been observed. The increase in strength with increasing days shall be attributed to the strengthening of hydrogen bond between the soil - β-glucan matrix. In addition to the thread linkages, coating of soil with biopolymer was also observed.

3.8 Cost benefit evaluation

California Bearing Ratio (CBR) of the untreated and treated soil was found to be 6.2% and 12.3 % respectively. The increase in CBR has contributed to reduced surface base course thickness of 40 mm for 20 MSA (Million Standard Axle), as per IRC: 37-2018. For a base course width of 3.75 m and length of 1 km, the decrease in base course thickness of 40 mm contributed to cost reduction of ₹15,57,052. β-glucan's price per kg is ₹275. Subgrade thickness was chosen as 500 mm as per IRC: 37-2018. Width and length of the subgrade was considered for 5.5 m and 1 km respectively. Cost benefit ratio was found to be 1.36. Thus, β-glucan treated subgrade is effective and economical in stabilization of expansive soil.

4 Conclusions

The results of the study points to the following conclusions.

pH and viscosity experienced negligible changes on addition of β-glucan to the soil.

Gel matrix test and dehydration test indicated that the β-glucan gel was promising and stable for 6 months duration.

Increase in optimum moisture content and Atterberg's limits indicate the hydrophilic nature of β-glucan.

β-glucan improves the shear strength of the high swelling clay. 2% addition of β-glucan led to 50% increase in unconfined compressive strength of the soil.

Durability test indicated that, even without cross linking of the biopolymer, the soil-biopolymer mixture did not decompose after 100 days.

SEM results show that the β-glucan – soil bonding has contributed to the strength development.

Cost benefit ratio was found to be 1.36, emphasizing the economical benefits of utilizing β-glucan.

These findings illustrate the benefits of β-glucan in real engineering applications when the focus is on strength improvement of the soil.

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