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Strength Characteristics of Kuttanad Soil Stabilized With a Biopolymer Guar Gum

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Abstract. Kuttanad soils are low strength soft clay or silt deposits found in the Kuttanad areas of the Alappuzha district, Kerala. Due to its low load-bearing and high shrinkage characteristics, the structures and pavements constructed over were unstable. Treatment with appropriate chemical additives is one of the accustomed and economic techniques in soil stabilization practice for improving the characteristics of weak soil. Traditional stabilizing agents like cement, lime, etc are becoming less environmentally friendly and costly. This paper focuses on the influence of a non-traditional soil stabilizer Guar gum which is a biopolymer on the strength characteristics of low strength and highly compressible Kuttanad clay soil. Biopolymers are environment-friendly polymers produced by living organisms like plants. The lack of sufficient research to understand its impact on soil behavior has minimized the use of biopolymers to become widely accepted for soil modification purposes. Samples prepared with varying dosages of biopolymer (0.5% -2.5%) were cured for a period of 7 to 28 days without moisture loss to study the influence of aging effect on strength parameters. Strength characteristics such as compaction, unconfined compressive strength, and California bearing ratio strength (CBR), etc. of stabilized samples were determined. Results showed that there is considerable improvement in the strength characteristics of soil with the inclusion of guar gum and with the curing period. Observing the tremendous improvement in the CBR strength value of soil within 28 days of curing, soil stabilization using guar gum may be recommended for effective and faster stabilization of weak subgrade soils for construction activities.

Keywords: Unconfined compressive strength, Biopolymer, Clay soil stabilization, Kuttanad Clay

1 Introduction

Clay soils are regarded as complex soils due to the undesirable characteristics it posses like low bearing strength and high shrinkage or expansive characteristics. All these make the soil prone to failure even at low loads and make the structure constructed above this unstable. Going for a deep foundation is often not cost-effective. An alternative to this is soil stabilization to alter its undesirable characteristics. Soil stabilization is unavoidable in many geotechnical engineering applications such as road or embankment construction, slope stabilization, erosion control, foundation, etc wherever undesirable characteristics of soils are encountered. Soil stabilization can be achieved by mechanical, physical, and chemical methods out of which chemical soil stabilization is most commonly preferred [1]. In many of the above situations where ground improvement is necessary, it may not be viable to use any of the methods alone. The situations may demand the usage of admixtures along with other methods or sometimes chemical soil stabilization alone to enhance the engineering characteristics of soil under consideration to the preferable value [2]. Stabilizing agents enhance the strength characteristics of weak subgrade soils resulting in reduced construction cost and improved performance. Significant amounts of the world's carbon dioxide (5–7%) and nitrogen oxide gas emissions occur during the production of conventional additives like cement, lime, etc. The production of these also accounts for around 15% of the total energy consumption in the global business sector [3]. This causes a high carbon footprint or high energy demand, leading to global warming. Hence the search for alternate additives in broader research areas resulted in the application of nanotechnology or biotechnology in soil stabilization. Bioenzymes, Nanomaterials, etc which can be grouped as nontraditional additives are dominant in recent years in the field of clay soil stabilization due to its advantages from sustainable point of view. These additives react faster, causes less energy demand in production and fewer carbon emissions. Hence they are eco-friendly. But the effects of these new generation additives on the properties of soil are still being researched.

Biopolymers are polymers that are produced by living organisms. These are stable, carbon-neutral, renewable, and hence environmentally friendly. The ultimate products of biopolymer decomposition are carbon dioxide, water, and ammonia [4]. Biopolymers have a broad spectrum of applications in agribusiness, biotechnology, processed food industry, chemical industry, power sector, environmental protection, and remediation [2]. Even from the 1940s, the utilization of biopolymers as a soil strengthening agent for soil was under consideration. Commonly used biopolymers for soil modification were Guar gum, Xanthan gum, Chitosan, Sodium alginate, etc. Different researches have been conducted in the past several years to understand the suitability of various biopolymers in improving soil properties and studies revealed that biopolymers are capable of enhancing soil properties considerably [5-8]. Some studies revealed that the unconfined compressive strength of soil enhanced more than 1.5 times with the biopolymer addition [9-11]. Toxicity studies on some of these biopolymers done by the World Health Organization (1987) found that they do not cause health hazards [2]. Hence biopolymer modification of soil can be considered as an ecologically sound technology in the field of ground improvement [2]. Based on a review of previous studies it is noted that, despite the beneficial properties of biopolymers, the lack of adequate research to understand their impact on soil behavior and the lack of standard methods for laboratory testing have prevented the use of biopolymers to become widely accepted for soil modification [12].

Kuttanad soils are soft highly organic clay or silt deposits with higher compressibility and lower strength characteristics found in the Kuttanad areas of the Alappuzha district in Kerala, India. Kuttanad comprises of Vembanad lake, and surrounding marshy land. These soils are unstable and had caused a lot of failures to the structures built over it. Hence studies are being conducted for the effective stabilization of

Kuttanad clays by imparting desired characteristics using stabilizing agents for improved performance.

A detailed summary of the laboratory test program conducted for finding the influence of a nontraditional environmental friendly soil stabilizer biopolymer, Guar gum on strength characteristics of Kuttanad soil such as compaction, UC strength, and CBR strength is presented in this paper.

2 Materials and Testing

2.1 Material characterisation

Soil. Clay soil studied was collected from the Champamkulam area of the Kuttanad region in the Alappuzha district of Kerala. The soil was collected at 1.5 m depth from ground level. It is dark grey. Untreated soil characteristics were determined according to IS specification and are given in Table 1.

Table 1. Untreated soil characterisation.

Property	Value
Clay content (%)	30
Specific gravity	2.66
Liquid limit (%)	65
Plastic limit (%)	31
Plasticity index (%)	34
IS classification	CH
Maximum dry density (kN/m^3)	15.2
Optimum moisture content (%)	21.2
Unconfined compressive strength (UC) (kN/m^2)	93
Soaked CBR strength (%)	2.9
Unsoaked CBR strength (%)	4.0

According to IS classification, collected soil is classified as inorganic clay of high plasticity from the plasticity chart. From Table 1, it can be inferred that the UC strength of base soil is moderately hard and is having low CBR strength.

Biopolymer. The biopolymer used in the study is Guar gum (GG) or guaran powder. Guar gum is dry cream-coloured powder and was procured commercially. It is cold - water- soluble. It is a galactomannan polysaccharide extracted from guar beans which are non-ionic. The main chemical constituent of guar gum is galactomannan which amounts to 75-85%. The main characteristic of guar gum is its ability to form viscous colloidal solutions when mixed with water. The chemical structure of the biopolymer is given in Fig. 1. Guar gum is obtained from seeds of the guar plant which is found in India. The guar seeds are mechanically dehusked, hydrated, milled, and screened according to their use [2].

Guar gum has a mannose: galactose ratio of approximately 2:1 [13]. The backbone in guar gum is a linear chain of β 1, 4 – linked mannose remains on which galactose residues are 1, 6 – linked at every second mannose, creating short side branches [14]. These are neutral polysaccharides with numerous hydroxyl groups. These hydroxyl groups are distributed in both main chains and side chains and form hydrogen bonding with each other which renders higher viscosity [15]. In polar solvents, guar gum swells on dispersal and form strong hydrogen bonding while in non-polar solvents it forms weak hydrogen bonding [16].

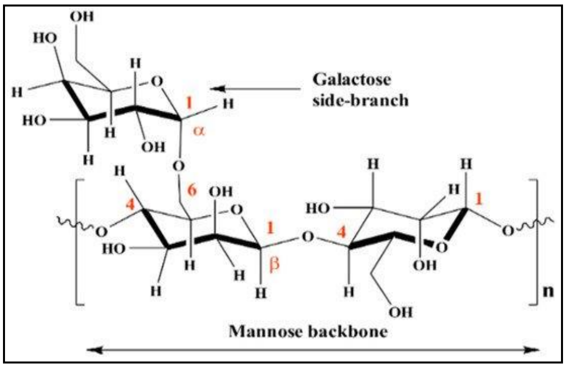

Fig. 1. Chemical structure of Guar gum [1]

In the soil-biopolymer mixture, a portion of the biopolymer enters the voids between soil particles while some portion sticks to the soil surface. Chemisorptions, hydrogen bonding, and physical adsorption by Vander Waals bonds are possible at the soil-biopolymer interfaces. The ionic or electrostatic bonds which are the primary bonds have the maximum bond energy and Vander Waals forces which cause physical adsorption to develop the weakest bonds [17]. As a result of bonding due to chemical reactions, a biopolymer encloses soil aggregates and interlinks to form a viscous and elastic membrane structure. These physicochemical reactions may usually take a few days. The modified structure causes an enhancement in the engineering characteristics of soil [10].

2.2 Specimen preparation and testing

Untreated soil is mixed with different proportions of Biopolymer guar gum powder and soil samples were prepared according to IS specification. Guar gum was added in varying contents of 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% by dry weight of soil taken for sample preparation to obtain soil- guar gum mixtures. Guar gum powder is mixed gently with water corresponding to OMC to avoid the formation of clumps and a homogenous solution is prepared. The soil was then mixed with this guar gum solution. Samples with varying contents of guar gum were prepared at maximum dry density (MDD) and optimum moisture content (OMC) of untreated soil and were stored in moistened conditions to minimize the loss of moisture. Prepared samples were cured without loss of moisture from 7 to 28 days before testing. All tests were conducted according to IS 2720 specification.

3 Results and Discussion

3.1 Compaction parameters

For studying the influence of curing period on strength characteristics, standard Proctor compaction tests according to IS 2720 Part 7: 1980 was conducted to determine the influence of biopolymer guar gum on MDD and OMC of treated samples after 7 days of curing period. Soil- guar gum mixtures were prepared at OMC and cured airtight in polythene bags for 7 days before the compaction tests were conducted. The compaction curves were obtained for various soil- guar gum mixtures and the influence of guar gum on OMC and MDD levels are shown in Fig. 2.

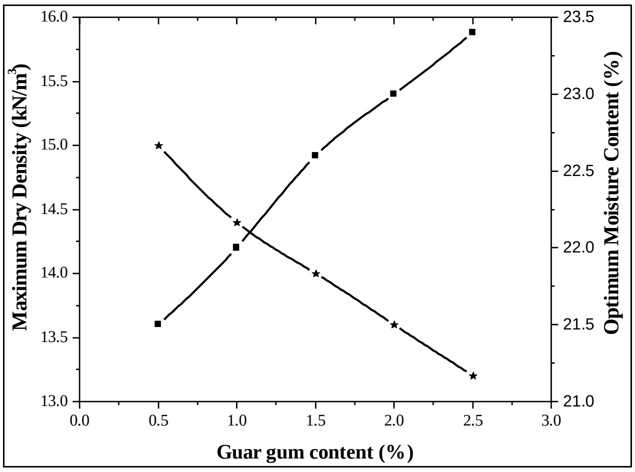

Fig. 2. Variation in compaction parameters with the addition of biopolymer guar gum after 7 days of curing

From Fig. 2, it can be seen that MDD decreases, and OMC increases with an increase in guar gum content. As the guar gum content increases from 0.5% to 2.5%, the MDD value reduces from 15.0 kN/m^3 to 13.2 kN/m^3, and corresponding OMC increases from 21.5% to 23.4%. It follows the same trend as the previous studies [19, 20]. As the amount of biopolymer guar gum increases, being a lightweight material, these biopolymers absorb water and form suspension with high viscosity and fill the spaces between the soil grains [18]. Due to the low weight of the fine particles along with the high viscosity nature of guar gum, it inhibits particle interaction and moves away from each other thereby increasing the overall void volume and results in decreasing the dry density of biopolymer treated soil. OMC increase is due to the increase in absorbed water utilized by the increased guar gum content. By increasing the solution concentration of biopolymer, the viscosity will increase, which will ultimately lead to more reduction in MDD.

3.2 Effect on Unconfined compressive strength

UCS tests were performed according to IS 2720 Part 10: 1991 under a constant strain rate of 1.2 mm/min on all combinations of soil - biopolymer mixture at different curing periods of 7, 14, and 28 days. For each guar gum-soil mixture, three similar cylindrical samples of 38mm dia. and 76mm ht. were prepared for UCS testing after 7 to 28 days of curing. These identical specimens of each mix were tested and axial stress vs strain curve are drawn. The peak axial stress values for each mix are taken from axial stress vs strain curves. The optimum content of guar gum is the content that gave maximum UCS value at all curing periods. UCS values of different dosages of biopolymer samples for curing periods of 7, 14, and 28 days are given in Fig. 3.

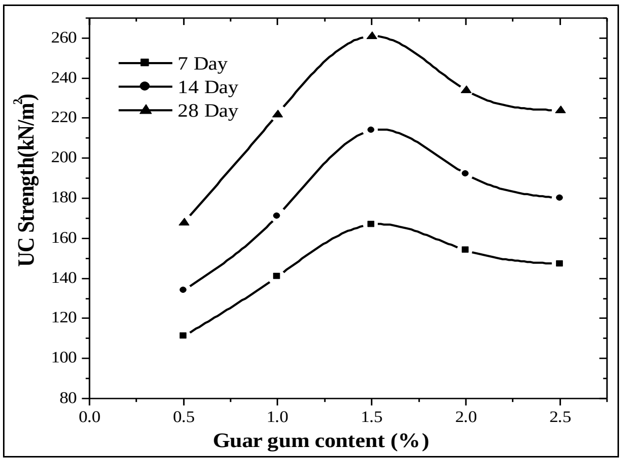

Fig. 3. Variation in UC strength with the addition of biopolymer guar gum for different curing periods

From Fig. 3, it can be seen that, as the biopolymer guar gum content increases, the unconfined compressive strength increases until 1.5% biopolymer content and after that, the trend gets reversed. This is the trend at all curing periods. Hence 1.5% guar gum content can be considered as the optimum content of guar gum for maximum strength development. The UC strength at 1.5% is 261kN/m^2 at 28 days of curing. Quantitatively the UC strength improved by 1.8 times the untreated clay soil strength. The higher strength enhancement with less aggregation and fewer voids is attributed to the cations bridging and hydrogen bonding between the electrically charged fine particles in the biopolymer and clay [20]. But beyond the optimal dosage of 1.5%, the reduction in UC strength is due to the higher viscosity with an increase in biopolymer content, which results in a lack of bonding between clay- guar gum- water mixtures.

It is also noted that UC strength value increases with an increase in the curing period from 7-28 days in the case of soil- guar gum mixtures. The increase in strength with curing may be due to less aggregation and fewer voids.

3.3 Effect on California bearing ratio strength

CBR strength testing was conducted according to IS 2720 Part 16: 1987 on all combinations of soil - biopolymer mixture at different curing periods of 7 and 28 days under both soaked and unsoaked conditions. For soaked CBR strength testing, prepared samples in CBR mould was soaked in water for 72 hours before conducting the test after covered curing. CBR strength values of soil- guar gum mixtures for curing periods of 7 and 28 days are given in Fig. 4.

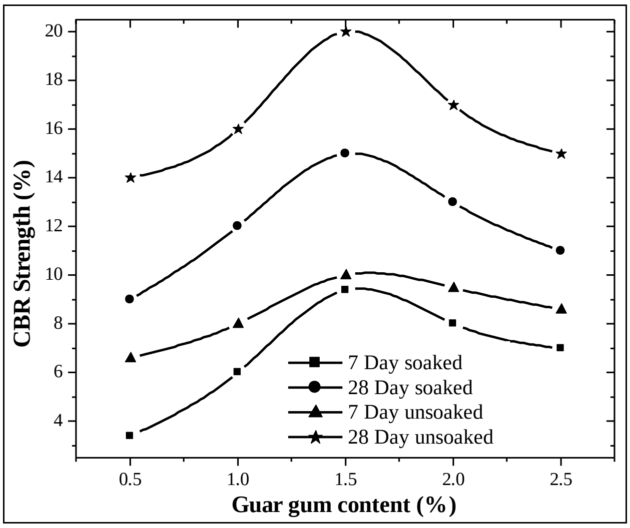

Fig. 4. Variation in CBR strength with the addition of biopolymer guar gum for different curing periods

From Fig. 4, it can be seen that, as the biopolymer content as well as curing period increases, CBR strength increases until optimum biopolymer content (1.5%) and after that CBR strength slightly reduces. This is the trend at all curing periods. From the results it can be seen that after 28 days of curing CBR strength of optimum biopolymer content added samples increased considerably i.e. by about 5 times the respective strength values of the untreated sample under both soaked and unsoaked conditions.

4 Conclusions

This paper highlights the study on the influence of biopolymer guar gum as well as curing period on strength characteristics of weak Kuttanad clay soil through a set of laboratory experiments including compaction test, unconfined compressive strength test, and California Bearing Ratio strength test. The main findings arrived at are:

1. According to IS classification, soil collected for the study from Champamkulam of Kuttanad region is clay of high compressibility (CH).
2. Untreated soil is having a high liquid limit, low UC strength, and CBR strength characteristics; which makes it unsuitable for load-bearing constructions.
3. With the addition of a biopolymer, the compaction characteristics of soil decreases.
4. The soil stabilised with 1.5% guar gum is the best soil –guar gum combination which exhibits maximum UC strength.
5. The UC strength and CBR strength of guar gum stabilized soil increased with the increase in the curing period and also with the increase in additive dosages.
6. With guar gum stabilization, the UC strength of soil improved by 1.8 times, and the CBR strength of soil improved by 4 times than untreated soil.

Hence from the above findings, it can be concluded that the application of biopolymer guar gum will be a cost-effective and efficient method in the stabilization of weak subgrade soils, although more studies are needed on the durability characteristics of biopolymer stabilized soil under different environmental conditions.

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