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Effect of Gellan Gum on Geotechnical Properties of Clayey Soil: An Experimental Study

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Abstract: Clay soil stabilization is a critical aspect of geotechnical engineering, as untreated clay often exhibits low strength, high plasticity, and poor workability. This study presents an experimental investigation into the stabilization of clayey soil using varying proportions of Gellan Gum, a natural, biodegradable biopolymer known for its eco-friendly characteristics. Gellan Gum was incorporated at dosages of 1.0%, 1.5%, and 2.0% by dry weight of soil to evaluate its effectiveness in enhancing the geotechnical properties of clay. A comprehensive suite of laboratory tests was performed, including Unconfined Compressive Strength (UCS), sieve analysis, Atterberg limits (liquid and plastic limits), and the Standard Proctor compaction test. The results demonstrated a significant increase in UCS values and a notable reduction in the plasticity index with increasing Gellan Gum content. Additionally, minor changes in compaction characteristics were observed, indicating improved workability. The findings highlight the potential of Gellan Gum as a sustainable and environmentally responsible alternative to conventional chemical stabilizers for improving the strength and consistency of problematic clayey soils.

Keywords: Biopolymer Soil Treatment, Gellan Gum, Clayey Soil Stabilization, Unconfined Compression Test.

1. Introduction

Clayey soils are widely encountered in construction and infrastructure projects; however, their engineering behavior often poses significant challenges due to low shear strength, high plasticity, excessive volume changes, and poor load-bearing capacity. These characteristics make clayey soils highly unsuitable for supporting structural loads without prior treatment. As such, soil stabilization becomes a crucial intervention in improving the mechanical and physical properties of clay to make it more suitable for construction activities. Traditional stabilization techniques commonly involve the use of cement, lime, and other chemical additives. While effective, these methods have come under scrutiny due to their high carbon footprint, long-term environmental impact, and detrimental effects on soil ecology. In response to these challenges, recent advancements in sustainable construction have shifted focus toward eco-friendly alternatives, especially biopolymers, as potential soil stabilizers. Biopolymers are naturally derived macromolecules produced by living organisms such as bacteria, algae, and plants. They exhibit a wide range of beneficial properties including biodegradability, low toxicity, renewability, and the ability to form gels or bind soil particles. Several biopolymers like xanthan gum, guar gum, and gellan gum have been experimentally studied for soil improvement, showing promising results in enhancing strength, reducing permeability, and improving cohesion. Among these, Gellan Gum stands out due to its excellent gel-forming ability, thermal stability, and biodegradability. It is an anionic, water-soluble biopolymer produced by Sphenodons elodea bacteria through fermentation. When mixed with soil and water, gellan gum forms a stable matrix that binds soil particles together, potentially increasing soil strength and reducing deformation under load. In geotechnical applications, Gellan Gum offers the advantage of being environmentally safe, making it a strong candidate for sustainable soil stabilization practices.

This study aims to evaluate the potential of Gellan Gum as a stabilizing agent for clayey soils by analyzing its effect on the soil's unconfined compressive strength (UCS), Atterberg limits, and compaction behavior. By varying the Gellan Gum content, the study investigates the extent of improvement in strength and workability, thus contributing to the growing body of research on sustainable geotechnical solutions.

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2. Materials And Methods

(a). ***Soil:*** The clayey soil used in this study was collected from Madanapalle, Andhra Pradesh, and its geotechnical properties were determined in accordance with relevant Indian Standard (IS) testing procedures.

(b). ***Gellan gum:*** The stabilizing agent employed was a commercially available low-acyl Gellan Gum powder. Gellan Gum is a high molecular weight anionic polysaccharide obtained through the aerobic fermentation of the bacterium Pseudomonas elodea (currently classified as Sphingomonas elodea). It is a multifunctional biopolymer known for its excellent gelling, stabilizing, binding, and thickening properties, making it highly suitable for use in soil stabilization applications.

2.1. Sample Preparation

The clayey soil used for this study was first oven-dried at 100°C for 24 hours to remove any inherent moisture and ensure uniformity in the experimental procedure. After drying, the soil was sieved and stored in airtight containers for further use. Soil samples were prepared by incorporating biopolymers—Guar Gum and Gellan Gum—in varying percentages of 1.0%, 1.5%, and 2.0% by dry weight of soil. The Guar Gum was first hydrated in the required amount of water and allowed to sit for 24 hours, sealed with cling wrap to prevent air entrainment and premature setting. Once the gel was fully hydrated, it was thoroughly mixed with the dried soil until a uniform and consistent blend was achieved. The Guar Gum–soil mix was then sealed in airtight bags and allowed to rest for 6 hours to attain moisture equilibrium. In parallel, the Gellan Gum powder was measured as per the specified dosage and heated at 100°C to activate its gelling properties. The activated Gellan Gum was then blended into the Guar Gum Soil mixture, ensuring complete homogeneity. The prepared samples were then subjected to a series of laboratory tests, including consistency limits (Plastic Limit and Liquid Limit), Standard Proctor Compaction Test, and Unconfined Compressive Strength (UCS) Test, to evaluate their geotechnical properties.

Fig.1 Plastic Limit

Fig.2 Unconfined Compression Test

Fig.3 Standard Proctor Compaction

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Table.1 Mix Proportion

Mix	Gellan Gum[%]	Total[%]
Mix 1	1.0	1.0
Mix 2	1.5	1.5
Mix 3	2	2

3. Results And Discussions

Examining the specific soil parameter allowed for the evaluation of the usefulness of Gellan Gum at different percentages (1%,1.5%,2%by weight of dry soil). Following are the conclusions of the study :complete analysis has done on the effects of biopolymers on soil characteristics .The Gellan Gum have the potential to be added to the soil as soil supplements ,since the results showed significant changes in soil properties .According to these results applying biopolymer to soil management techniques is important since they may improve soil quality and encourage sustainable methods .The main results of this study are presented on Table.2.

Table.2 Test Results

Mix	Mix 1	Mix 2	Mix 3
Liquid limit [%]	75	82.00	**88.00**
Plastic limit [%]	44.80	50.00	**54.89**
Shrinkage limit [%]	26.31	32.18	**38.56**
Maximum Dry Unit Weight [kN/m²]	18.88	18.53	**18.39**
Optimum Moisture Content [%]	24	22	**21**
Permeability ×10^4 [cm/s]	9.832	6.420	**3.198**
Unconfined Compressive Strength [kN/m²]			
0 Days	194.31	230.81	**253.77**
7 Days	258.81	341.00	**39998**
14 Days	**312.19**	**333.23**	**417.65**

3.1. Consistency Limits

Gellan Gum were used as stabilizers since they are naturally available and sustainable. The liquid and plastic limit of treated soil rise with Gellan Gum content. Since Gellan Gum get activated and they form hydrogels. The bonding activity becomes stronger by hydrogen bonds. Similarly, shrinkage limit also increases. Increase in Gellan Gum content added increases shrinkage limit as they shrink rapidly upon drying. Thereby shrinkage limit gets increased. Plastic limit doesn't show great variation as soil gets stiff due to bonding of molecules. Viscosity and adhesion of soil biopolymer mix increase with addition of Gellan gum biopolymer. Consistency limit. On comparing treated and untreated soil, Liquid limit has increased from 59% to 88%. Liquid limit is maximum for Mix 3. The plastic limit gradually increased from 32.18% and shrinkage limit from 21% to 38.56 %. This result indicates the enhancement in compressibility of soil.

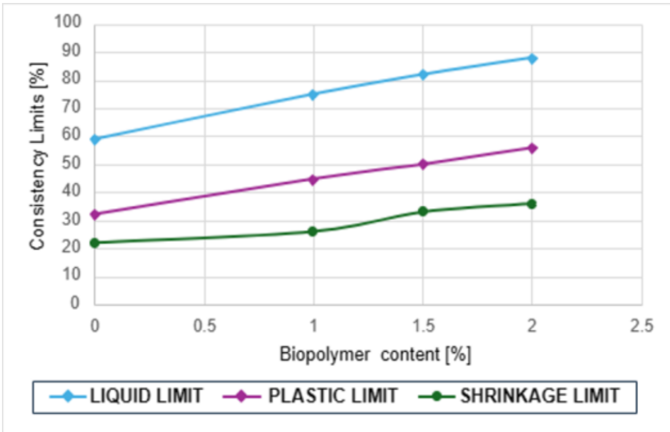

Fig.4 Consistency Limits

3.2. Compaction

Permeability and strength of soil are determined by its density and void ratio. Gellan gum contributes a small increase in soil density but decreases the ideal moisture content. The basis for this is that Gellan gum makes the soil more cohesive and compact by absorbing water and forming hydrogels. Even if the soil has less density, a higher biopolymer content results in stiffer soil and low moisture content. Fig.5 Compaction characteristics of different biopolymer contents. Dry density of treated soil shows increases and its optimum moisture content decrease with increase in biopolymer content. The ability to compact treated soil at low energy is indicated by a change in dry density over a range of water content.

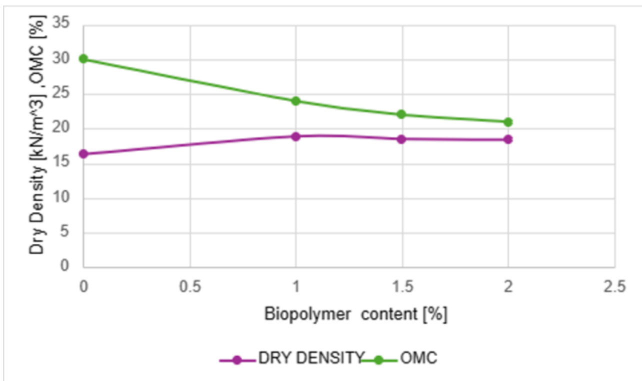

Fig.5 Compaction characteristics of different biopolymer contents.

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3.3. Unconfined Compression Test

Gellan Gum are added to soil to create a tight link between the particles, which significantly boosts the unconfined compressive strength of soil. A hard soil biopolymer matrix with small gaps and stronger hydrogen bonding is produced by viscosity of Gellan Gum solutions. However, at low biopolymer content, the soil undergoes constant deformation, reducing strength. As biopolymer content increases, soil stiffness improves. The viscous gum solution action and hydrogels creation are mainly responsible for the strength gain. Fig.6 Effect of curing period on the strength of treated soil The compressive strength of soil biopolymer mix is seen increasing with increasing curing period that is compressive strength of treated soil with 14 days (about 2 weeks) curing shows more strength than noncured treated soil.

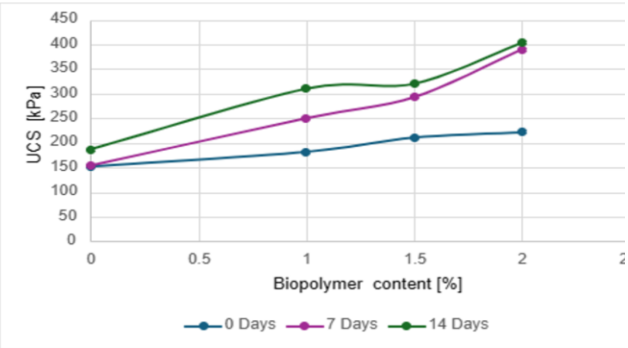

Fig.6 Effect of curing period on the strength of treated soil

4. Conclusions

In this study improvement of weak soil by using sustainable & environmentally friendly Gellan Gum biopolymers. Because of its strong bonding properties, the usage of biopolymers, such as Gellan Gum, has shown a notable improvement in soil qualities. Maximum change in geotechnical properties is shown by the results at 2%addition of biopolymers. When soil is treated with biopolymer, the liquid and plastic limits rise. The maximum dry density rose from 16.31kN/m3 to 18.39kN/m3 , whereas the optimal moisture content decreased by 6%. In treated soil a reduction in percentage of void ratio was observed.

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