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Modifying Expansive Soil Characteristics with Xanthan Biopolymer Integration

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Abstract: Expansive soils pose significant challenges in various engineering projects due to their tendency to swell and shrink with changes in moisture content. Traditional stabilization methods often come with environmental and economic drawbacks. This research paper explores the potential of xanthan biopolymer, a polysaccharide of microbial origin (Xanthomonas Campestris), as a sustainable and effective alternative for altering the engineering properties of expansive soils. Through laboratory experiments and analysis, the paper investigates the influence of xanthan biopolymer on key soil properties such as swelling behaviour, shear strength, and permeability. The findings provide insights into the feasibility and efficacy of using xanthan biopolymer for soil stabilization, offering a promising avenue for sustainable geotechnical engineering practices.
Keywords: Expansive soil, Swelling, Shrinkage, Stabilization, Xanthan gum, Xanthomonas campestris

I. INTRODUCTION

Human population on our planet is ever increasing and so are the number of residential structures. Due to the expansion of urban areas, people are now being forced to construct upon problematic soils, such as the expansive ones which pose a threat to the stability of the structure built on it, hence stabilization of such soils is a concern for the engineers. Improvement in swelling-shrinkage behaviour, compressibility, strength and erosion resistance is the goal of stabilization of soil so that it can be used for construction purposes. Methods of stabilization include physical and chemical methods, of which the physical method involves compacting the soil, heat treatment to the soil, vibratory treatment, etc., compaction being the most used process for densification of soils. Drainage of the soil is also done to remove excess pore water pressure resulting in increased effective stress. Chemical methods use admixtures to help in proper soil compaction or reducing the hydraulic conductivity. Effective chemicals form non-water-soluble precipitates which are hard in nature.

This research work is performed to understand the physical and chemical changes occurring in expansive soils with the addition of Xanthan Bio-polymer in various proportions, to the dry weight of expansive soil.

II. LITERATURE SURVEY

Findings of various researchers and scholars which served as a guide in this research work have been listed below:

Latifi et.al. (2016), The results from both macro and microscale experiments were presented to investigate the behaviour and attributes. The stabilization of cohesive soils using xanthan biopolymer. Soils under examination were mainly montmorillonite and kaolinite clays. Objective of the study involved adjusting the xanthan content within the range of 0.5% to 2.5% relative to the dry soil weight. Significant increase in the Unconfined Compressive Strength was observed for 1% addition of Xanthan.

Chang et.al. (2014) They experimentally demonstrated the variation in characteristics of expansive soil mixed with Xanthan Gum. They evaluated the strengthening characteristics and long-time durability of different soil samples subjected to treatment with the biopolymer xanthan gum, considering factors for example, techniques like blending methodologies, composition of the soil, and the ratio of biopolymer addition. The study concluded that a concentration of 1% to 1.5% of xanthan gum appeared to be the most efficient and economical.

Chen et.al. (October, 2013) have introduced a comprehensive research initiative focused on harnessing biopolymers to enhance the stability and erosion resistance of Mine Tailings. Their study delved deeply into enhancing the undrained. The shear strength (Su) of a mine Tailings by incorporating natural biopolymers such as xanthan gum or guar gum. They demonstrated that increasing the biopolymer content correlates with higher Atterberg limits, and observed that on increasing the guar gum content from 0% to 2% the variation in the undrained shear strength of the mix went from 1.50 to 22.00 kPa whereas an increase from 1.50 to 5.40 kPa was observed on virgin soil and up to 3% xanthan biopolymer variation.

Additionally, the scholars suggested 2 equalities after comparison of their undrained shear strength findings with the earlier established empirical equations from an existing literary source, aimed at predicting the undrained shear strength of Mine Tailings mixed with a biopolymer.

Qureshi et.al. (2017) demonstrated the strength and slake durability characteristics of biopolymer-treated sand from the Al-Sharqia Desert in Oman, comparing it with cement-treated sand. The study showed that achieving peak performance concerning both strength and durability. was achieved with 2-3% xanthan gum content by weight of the soil, leading to increased UCS and resistance to disintegration upon interaction with water.

Chen et.al. (2014) Researched application of naturally occurring biopolymers such as xanthan/guar, for stabilizing mine tailings (MTs) to control dust. They conducted tests to understand the ability to hold water and resist wind erosion in samples treated with biopolymers. Results showed that xanthan gum and guar gum effectively improved the ability to hold water and manage dust, while also providing Significant strength surpassing mere water wetting.

Chang et.al. (2015) He studied the effect of introduction of two thermos-gelation biopolymers for the treatment of soil, which showed promising prospects for enhancing its strength due to clay interacting through hydrogen bonding. They treated sandy and clayey soils with different biopolymer concentrations and found promising results in properties of compressive strength of soil and its durability, both on land and waterfront.

Nakamatsu et.al. (2017) studied the behaviour of foundation soil, treated using biopolymer carrageenan, which caused increased water resistivity, erosion resistance, and mechanical properties of adobe construction.

Chang et al. (2017) illustrated how Jumunjin sand, when treated with gellan gum, showed resilience and usability. They observed that repeated wetting and drying cycles gradually reduced the strength of the sand treated with gellan gum. However, they also noted that the sand exhibited some level of strength restoration even after undergoing multiple cycles of wetting and drying.

Etemadi et.al. (2014) performed experiments in a laboratory setting using soil that had been treated with 5 distinct biopolymers: xanthan, guar gum, chitosan, polyhydroxy butyrate, and poly glutamic acids for stabilization of subsurface heavy metals. These biopolymers were found to improve soil characteristics, decrease permeability, increase shear strength, and enhance metal uptake capacity while reducing leachability.

III. MATERIALS

This section outlines the approach and resources utilized to meet the outlined goals. Laboratory preparation was undertaken to mimic the properties of expansive soil, particularly black soil when treated with a biopolymer (specifically, xanthan gum powder obtained commercially) at different concentrations and curing durations for stabilization. “The process of sample preparation, sampling, and testing techniques employed for material characterization, along with the specifics of the experimental arrangement for investigation will be presented in the coming sections.

A. Expansive Soil

The black soil (expansive soil) utilized for the investigation originates at Sonebhadra, U.P. This soil exhibits a liquid limit of 53%, indicating its significant expansiveness. Subsequently, various quantities of sodium bentonite were incorporated into the soil. The sodium bentonite was sourced from an online store. Through experimentation, it was found that adding 30% bentonite resulted in a liquid limit of 86% for the mixture, signifying a highly expansive soil composition.

B. Xanthan Gum

The biopolymer was procured from an online dealer (India Mart). It typically has a pH range of 6 to 8. This substance, known for its rheology modification capabilities, was first discovered in the 1950s. It's a natural anionic polysaccharide consisting of D-glucuronic acid, D-mannose, pyruvate mannose, 6-O-acetyl D-mannose, and a 1,4-linked glucan (Garcia-Ochoa et al., 2000; Hassler and Doherty, 1990). One of its key characteristics is its pseudoplasticity (Milas & Rinaudo, 1986) and high shear stability (Chen & Sheppard, 1980), even at low concentrations. Additionally, it exhibits desirable properties such as pH stability, storage stability, and compatibility with ionic salts (Hassler & Doherty, 1990). Due to these properties, xanthan gum finds extensive applications across various industries including cosmetics, oil, paper, paint, pharmaceuticals, food, and textiles. It is used as a gel forming, thickening agent, or suspension forming agent, as well as a flocculating agent or for keeping viscosity in check.

IV. METHODOLOGY

Samples of expansive soils with varying percentages of Xanthan Gum (0%, 0.2%,0.5%,0.8% and 1%) were used to prepare samples in this study. Following tests and calculations were conducted on these samples:

1) Specific Gravity
2) pH
3) Distribution of Particle Size
4) Limits of Consistency (liquid, plastic and shrinkage limits)
5) Linear shrinkage
6) Compaction tests (heavy and light compaction as per IS codes)
7) Swell Pressure
8) Consolidation Test (as per IS 2720-part- 15 1965)
9) Unconfined Compressive Strength (UCS)
10) Freeze and Thaw Durability Test
11) X – Ray Diffraction (XRD)
12) Scanning Electron Microscopy

V. RESULTS

This section discusses the results of an experiment conducted for stabilization of expansive soils by mixing of biopolymer. The sample consisted of expansive soil mixed with different percentages of xanthan gum (0.2%,0.5%,0.8% and 1%) The experiment involved conducting IS light and IS heavy compaction tests for determination of the optimum moisture content along with maximum dry density for both untreated samples and samples treated with biopolymer. Atterberg limits were analysed to observe any changes in plastic behaviour of the treated and untreated expansive soil. Additionally, the study investigated swelling, consolidation, strength, and durability behaviour of the treated soil samples. Each set of results is thoroughly examined to comprehend the relationship between the geotechnical properties enhanced as a result of mixing the Xanthan Gum with soil.

A. *Specific* Gravity

The table below displays the specific gravity values of various xanthan gum and soil mixtures. It is to be noted that with the concentration of biopolymer increases, the specific gravity decreases.

TABLE. 1
Specific Gravities for Virgin and Soil-Biopolymer Mixes

Soil Type	Specific Gravity (G_s)
Untreated Soil	2.74
Soil and Xanthan Gum (0.2%)	2.68
Soil and Xanthan Gum (0.5%)	2.68
Soil and Xanthan Gum (0.8%)	2.67
Soil and Xanthan Gum (1.0%)	2.27

B. *pH*

The pH level of the soil measures 5.9, indicating a slight acidity. The reaction process of medium and the xanthan gum can get affected due to the pH of the environment (Thakur et al., 2011). when acidic environment is present, xanthan monomer release [H^+] from the (RCOOH) groups, (Bueno et al., 2012). Conversely, when the environment is basic, xanthan monomers release hydrogen ions from the ester groups present in them (RCOOR'), which results in a higher tendency to swell in comparison to the acidic groups of the xanthan gum. pH levels of xanthan typically vary from 6 to 8, as indicated on its container. When added to soil, it marginally raises the soil's pH. Further pH test results are provided in Table 6 for detailed information.

TABLE. 2
Result of pH test for Treated and Untreated Soil

Soil Type	pH
Untreated Soil	5.8
Soil and Xanthan Biopolymer (0.5 %)	6.1
Soil and Xanthan Biopolymer (1.0 %)	6.1

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C. Atterberg Limits and related values

The liquid limit of the soil is a measure of the amount of water which is needed to satisfy demand of the diffuse double layer present around the particles of soil. Figure no. 1 illustrates plastic and liquid limit for the samples at different time intervals and Xanthan Percentage. The increase in both of the limits is attributed to the hydrophilic behaviour of xanthan monomers present in mixture.

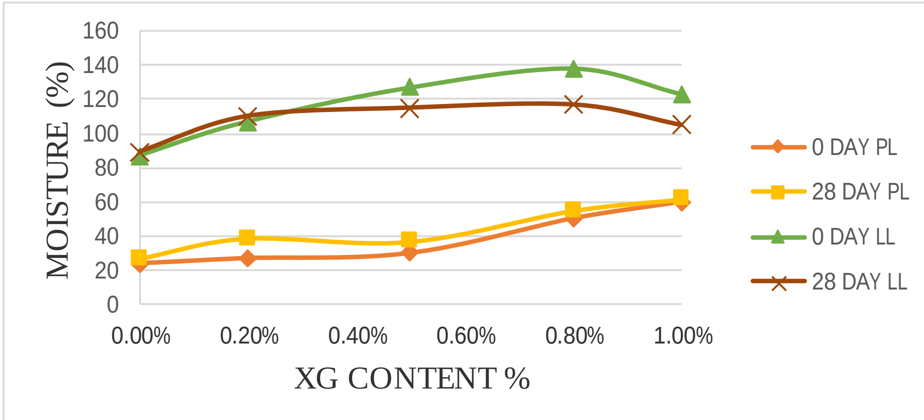

Fig.1. Variation In liquid Limit and Plastic Limit with Different Mix and Saturation Period

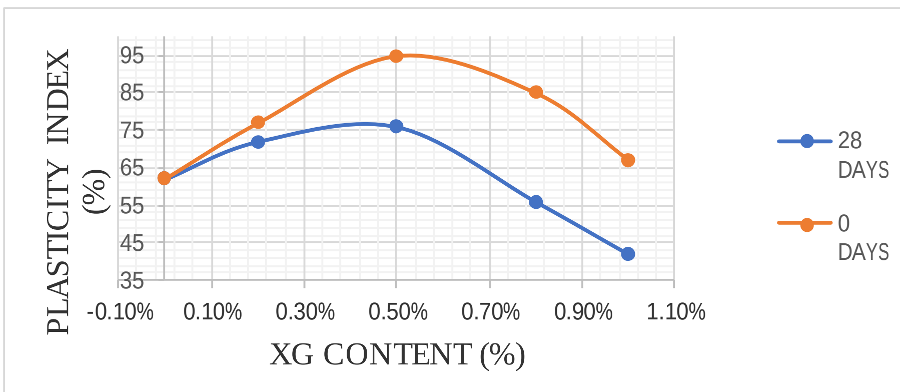

Fig.2. Plasticity Index for biopolymer(%age) and Saturation Period

D. Linear shrinkage

Table No. 3 Shows the variations in the linear shrinkage under different xanthan gum concentrations. Xanthan gum alters the rheology of the fluid, thereby increasing the pore fluid density within the treated soil matrix. During dewatering, the high-density pore fluid in the treated soil evaporates more slowly compared to untreated soil. Consequently, this slows volume change of the sample. This caused the Treated soil to exhibit increased volumetric shrinkage and at the same time a reduction in the value of linear shrinkage

TABLE.3
Linear Shrinkage for Soil-Biopolymer Mix

Variation of Concentration	Observed Linear Shrinkage
Untreated Mix	24.30 %
Soil and Xanthan Gum (0.2%)	24.10 %
Soil and Xanthan Gum (0.5%)	23.80 %
Soil and Xanthan Gum (0.8%)	23.80 %
Soil and Xanthan Gum (1.0%)	23.60 %

E. MDD and OMC results

Figure 3 and Figure 4 depict the compaction curves for expansive soil treated with xanthan gum, illustrating variations in MDD and OMC as the concentration of xanthan gum increases. The experimental findings reveal that, under light compaction, the dry density decreases from 16.09 kN/m3 to 15.91 kN/m3 with increasing xanthan gum concentration. Conversely, under heavy compaction, the dry density shows slight increment from 17.42 kN/m3 to 17.60 kN/m3 as xanthan concentration increases from 0% to 1%. The reduction of OMC from 17.40% to 15.69% for light compaction is observed with an increase from 21% to 22.1% under heavy compaction as the concentration of biopolymer increases

TABLE.4.
OMC and MDD for the soil sample

Standard Compaction		Modified Compaction	
OMC (%)	20	OMC (%)	17.4
MDD (KN/m^3)	16.096	MDD (KN/m3)	17.42

TABLE.5
Results of Heavy/ Light Compaction Tests for different values of Xanthan in the expansive soil.

MIX	Heavy Compaction		Light Compaction	
	OPTIMUM MOISTURE CONTENT (%)	MAX DRY DENSITY (KN/m3)	OPTIMUM MOISTURE CONTENT (%)	MAX DRY DENSITY (KN/m3)
Soil	17.4	17.42	20.98	16.08
Soil and XG (0.20%)	16.8	17.46	21.4	15.84
Soil and XG (0.50%)	16.30	17.45	21.33	15.17
Soil and XG (0.80%)	16.09	17.52	21.6	15.46
Soil and XG (1.00%)	15.69	17.60	22.0	15.90

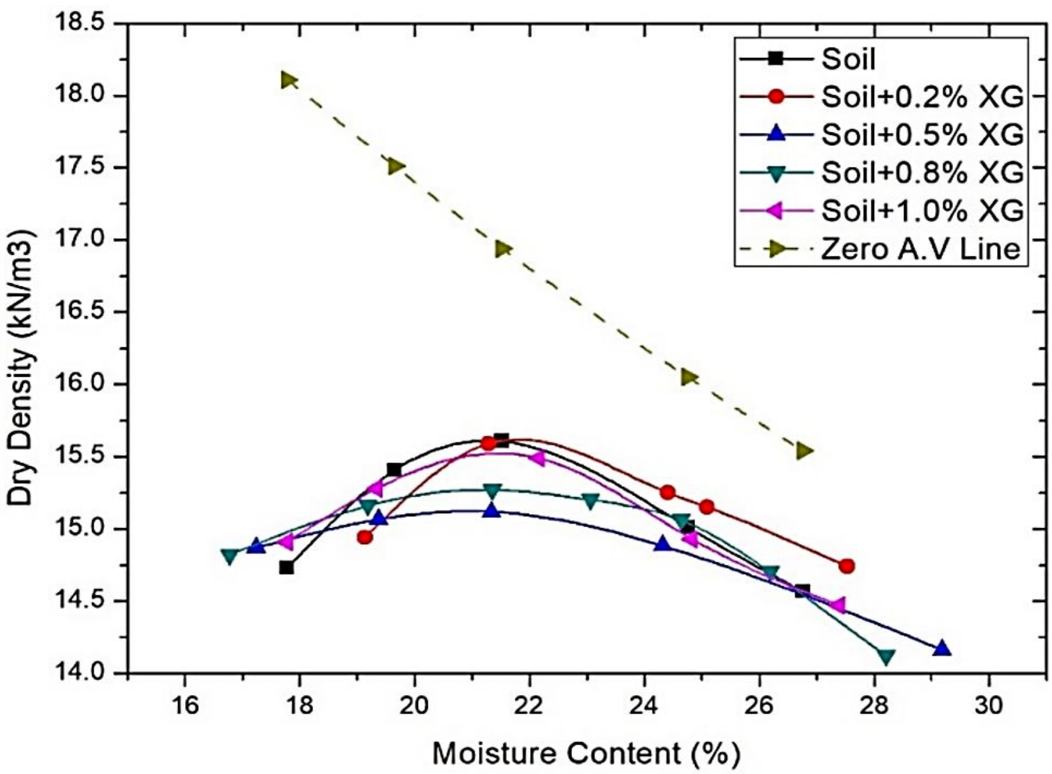

Fig.3. Standard Compaction Curve for Increasing Xanthan Concentrations

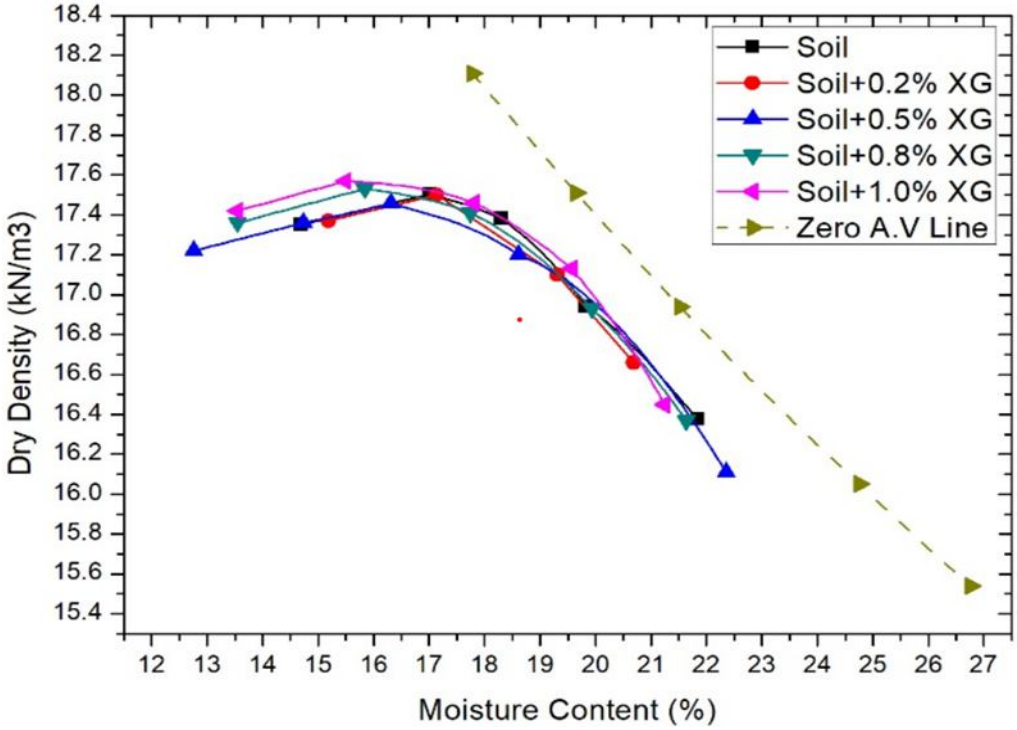

Fig.4. The Modified Compaction Curve for increasing Xanthan Concentrations

F. Unconfined Compressive Strength

Generally, the soil treated with xanthan exhibits a significant increment in the strength as compared to untreated soil, as depicted in Figure 5. This suggests that the treatment with xanthan gum enhances the cohesiveness and elastic modulus of soil mix. Treating with xanthan gum boosts the compressive strength of biopolymer-soil matrix from 984.77 kPa to 1170.98 kPa for immediately performed unconfined compressive strength tests and up to 1900.84 kPa for samples cured for 28 days with a 1% xanthan gum mixture. The strength improvement is attributed to the bond between the xanthan gum and soil grains.

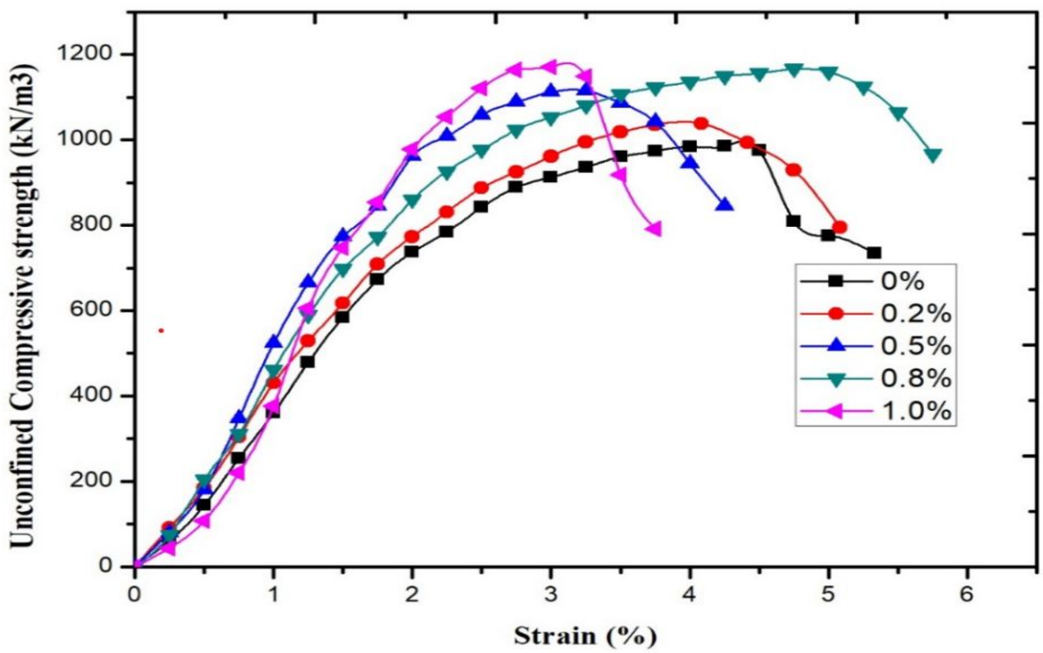

Fig.5. UCS Graph (Soil + Xanthan Gum) – Immediate Testing

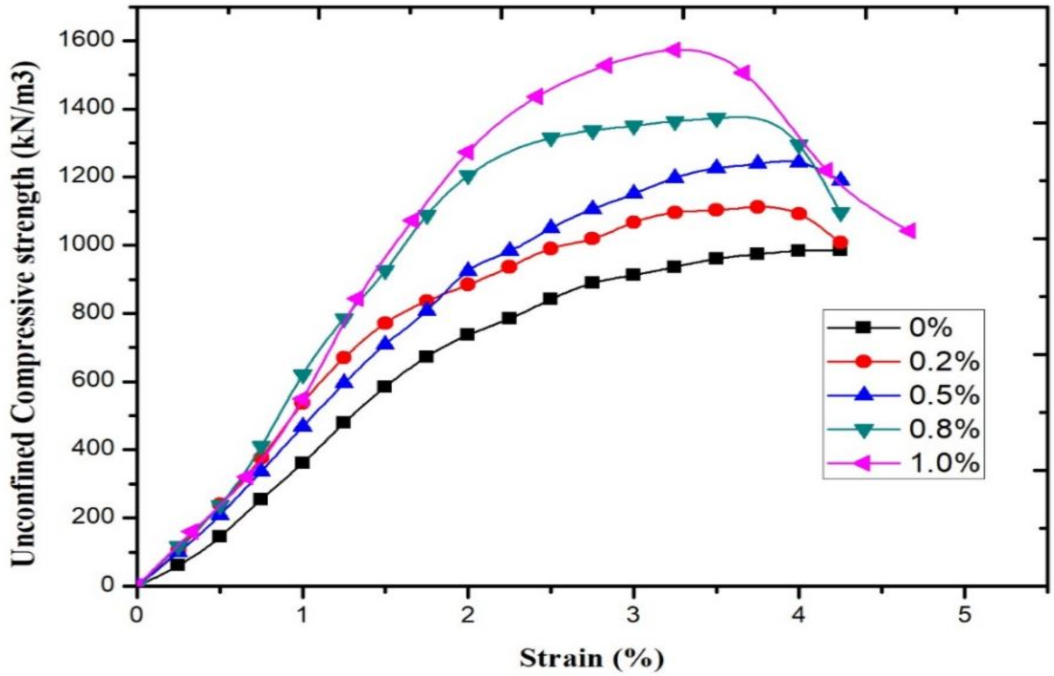

Fig.6. UCS Graph (Soil + Xanthan Gum) – 3 days curing

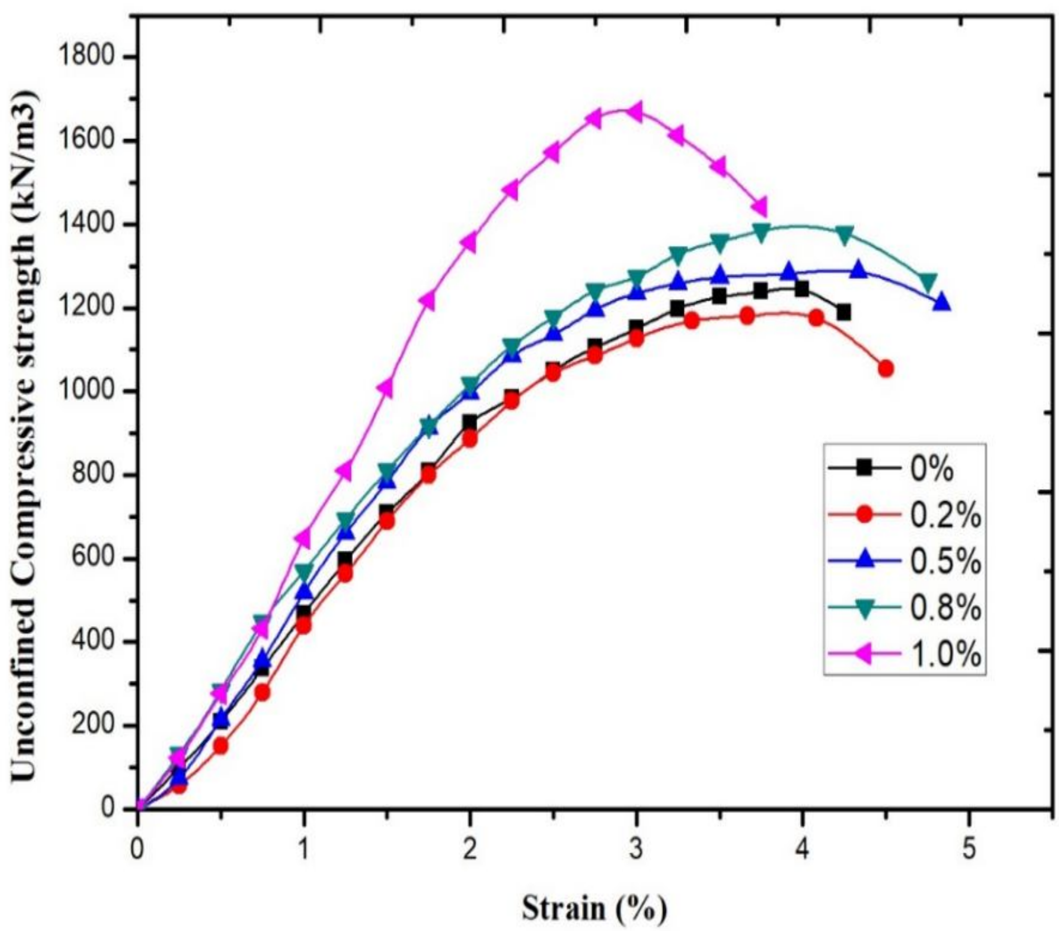

Fig.7. UCS Graph (Soil + Xanthan Gum) – 7 days curing

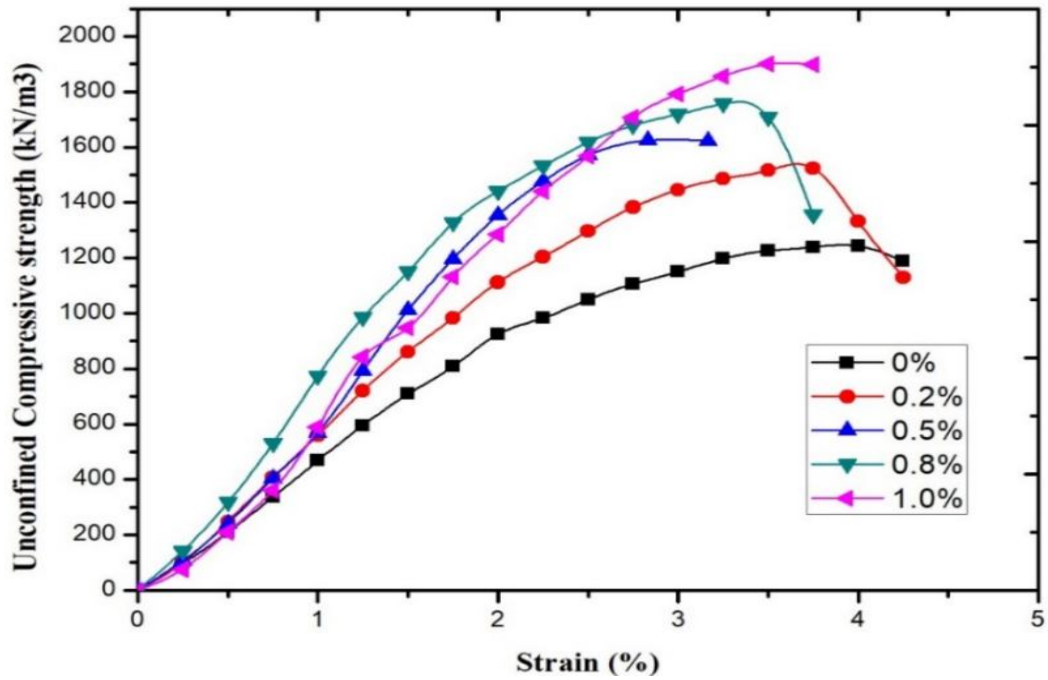

Fig.8. UCS Graph (Soil + Xanthan Gum) – 28 days curing

G. Stress-Strain values

TABLE.4

Changes in Stress/Strain due to increment in biopolymer Content for different curing periods

Percentage of Xanthan Gum	0 day		3 Day curing		7 Day curing		28 Day curing	
	Stress	**Strain**	**Stress**	**Strain**	**Stress**	**Strain**	**Stress**	**Strain**
0.00 %	984.77	4.24	984.77	4.32	984.77	4.82	984.77	3.24
0.20 %	1038.38	4.07	1103.20	3.40	1180.68	3.66	1528.85	3.74
0.50 %	1115.76	3.24	1243.55	3.98	1282.11	3.91	1628.17	2.82
0.80 %	1165.91	4.74	1372.38	3.40	1377.70	3.98	1703.46	2.47
1.00 %	1170.98	2.98	1573.16	3.24	1669.36	2.99	1900.84	3.40

H. Elastic Modulus variation with Xanthan Gum Percentage

TABLE.5

Variation OF Elastic Modulus with Increase in XG% and time of curing

Xanthan Content (%)	0-day curing	3 Day curing	7 Day curing	28 Day curing
	Elasticity Modulus (in KN/m^2)			
0	169.58	169.58	169.58	169.58
0.2	179.46	304.71	321.70	433.11
0.5	207.20	369.47	394.4	499.74
0.8	208.54	415.53	461.77	540.47
1.0	253.69	484.04	556.45	584.87

I. 1-D consolidation

The findings indicate that for the increase in biopolymer content in the soil, the hydrogels of xanthan occupy the voids of soil, leading to pore blockage by the highly viscous gum. Consequently, this impedes the passage of free water inside the soil voids.

TABLE.6
Variations in Cc and Cs with %XG in Soil

Percentage of Xanthan (%)	Recorded Value of Compressibility Index (Cc)	Recorded Value of Swelling Index (Cs)
0 %	00.49	00.030
0.5 %	00.53	00.063
1.0 %	00.53	00.066

TABLE.7
Changes in C_v under various mix compositions and consolidation pressures.

Mix Type	Pressure Readings (Kg/cm^2)	Permeability Values (K)(centimetres/sec)	Cv (m^2/s)
Soil	0.2 - 0.4	2.39440×10^{-11}	0.0001
	0.4 - 0.8	4.42295×10^{-11}	0.00011
	0.8- 2	7.73760×10^{-11}	0.0002
	2- 4	6.78944×10^{-11}	$7.1\times10^{-0.5}$
	4 – 8	2.74303×10^{-11}	$5.8\times10^{-0.5}$
Soil and XG (0.5%)	0.2- 0.4	8.84303×10^{-11}	8.5×10^{-5}
	0.4- 0.8	9.54044×10^{-11}	8.2×10^{-5}
	0.8 – 2	8.82364×10^{-11}	8.0×10^{-5}
	2- 4	6.99074×10^{-11}	7.6×10^{-5}
	4 – 8	3.26245×10^{-11}	7.1×10^{-5}
Soil and XG (1.0%)	0.2-0.4	1.39540×10^{-10}	9.4×10^{-5}
	0.4 - 0.8	1.87640×10^{-10}	8.4×10^{-5}
	0.8- 2	1.52294×10^{-10}	7.0×10^{-5}
	2- 4	6.38884×10^{-11}	5.7×10^{-5}
	4 -8	2.59574×10^{-11}	4.3×10^{-5}

J. Scanning Electron Microscopy

Figure No. 9, SEM images depict the typically flaky grains of the soil at 3000X and 5000X magnifications. The virgin soil shows undulated and flaky particles with numerous voids. Conversely, Figures 10 and 11 illustrate samples cured for 3 and 28 days at 1.0% xanthan content, showing larger soil particles with fewer voids.

This indicates that these small clay grains are enveloped by a gummy and cementitious type material, resulting in the formation of larger agglomerated clay particles. This phenomenon is attributed to the direct interaction between clay particles and xanthan monomers through hydrogen bonding and electrostatic bonding.

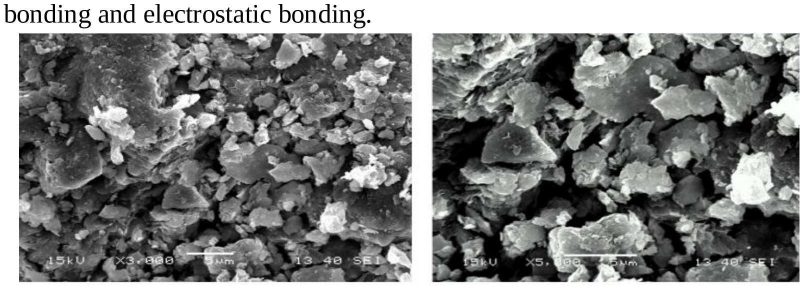

Fig.9. Scanning electron microscope (SEM) analysis (untreated soil captured at magnifications of 3000X and 5000X)

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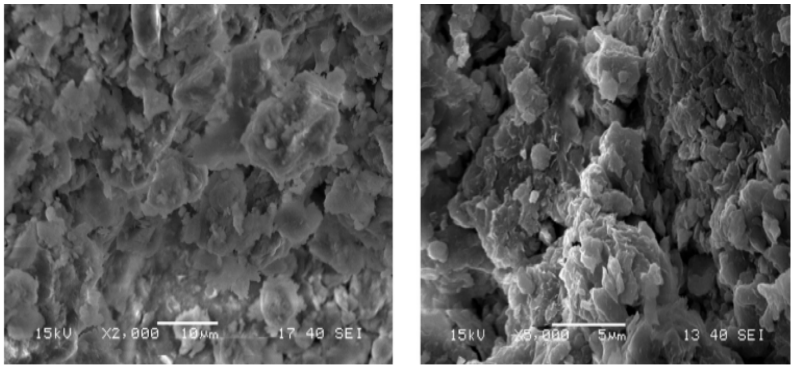

Fig.10. Scanning electron microscope (SEM) analysis (1% xanthan gum + soil, 3 days curing, magnifications of 3000X and 5000X)

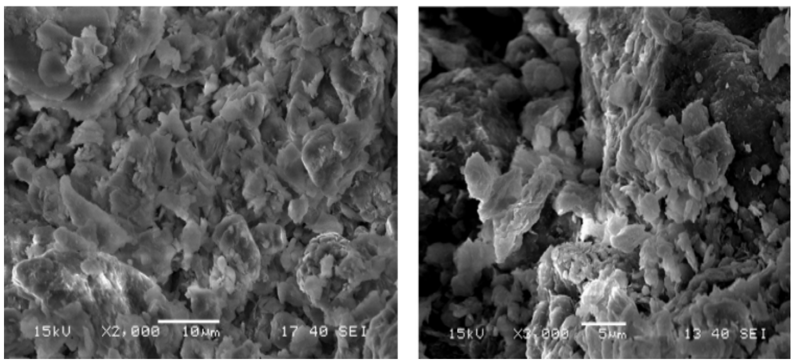

Fig.11. Scanning electron microscope (SEM) analysis (1% xanthan gum + soil, 28 days curing, magnifications of 3000X and 5000X)

VI. CONCLUSIONS

This research investigates about the geotechnical effects of using xanthan gum to stabilize expansive soil. The treatment of black soil with xanthan gum at varying %ages yield significant results, as discussed below based on experimental findings:

1) Increasing the concentration of biopolymer, such as xanthan gum, raises the soil's liquid limit (LL) due to increased viscosity of pore fluid. However, at concentrations in the range of 0.8% and 1.0%, particle accumulation surpasses the viscosity increase, resulting in a slight decrease in the clay particles' surface area and consequently a minor decrement in the liquid limit.
2) The same mechanism affects the plastic limit, leading to a consistent increase in plastic limit for both immediate and 28-day tests with rising xanthan gum concentrations.
3) Enhanced pore fluid viscosity from increased xanthan gum content aids in the reduction of the rate of evaporation of liquids from the treated soil, thus causing decreased volumetric change and shrinkage, but increased linear shrinkage.
4) The increased viscosity of the pore fluid due to increased xanthan gum content induces particle flocculation through a high-viscosity diffuse double layer, that resists the impact of standard compaction. This results in an increase in the optimum moisture content (OMC) and maximum dry density (MDD) of the treated soil. However, under heavy compaction, increased energy facilitates lubrication, resulting in a slight increase in MDD.
5) Xanthan gum exhibits a significant strengthening effect on treated soil, with a strength increment of approximately 93% at 1% of xanthan concentration. The strengthening is attributed to the direct interactions between negatively charge on the soil particles and the activity of carboxylic group of the xanthan gum, such as hydrogen bond formation and cation bridging.
6) Initial swelling with slight increase of 7.68% in the DFS is observed, after seven days of curing, particle agglomeration reduces the specific surface area, resulting in reduced water absorption and a decrease in swelling by 29.84% for a xanthan gum substitution of 1%.
7) Swell pressure tests reveal a reduction of 13.51% in swelling pressure for immediately tested samples at 1% xanthan gum concentration, and a reduction of 54.05% after seven days of curing compared to virgin soil.

8) Consolidation tests demonstrate that the mixing of the xanthan biopolymer increases the compressibility index (Cc) by approximately 4.00 % at the xanthan concentrations of 0.5% and 1.0%, while moderately increasing the swelling index (Cs). Additionally, it causes a reduction in the value of hydraulic conductivity but prolongs the period of consolidation settlement with increment in xanthan content.

9) Freezing /thawing durability test shows positive test results for increasing xanthan %. Expansive nature is exhibited by the soil due to its natural affinity for water absorption, causing increased volumetric changes on increasing biopolymer %. The increased pore fluid viscosity causes a decrease in the rate of evaporation, further aiding in reducing the loss of moisture content and providing resistance against the loss of mass in freezing /thawing tests.

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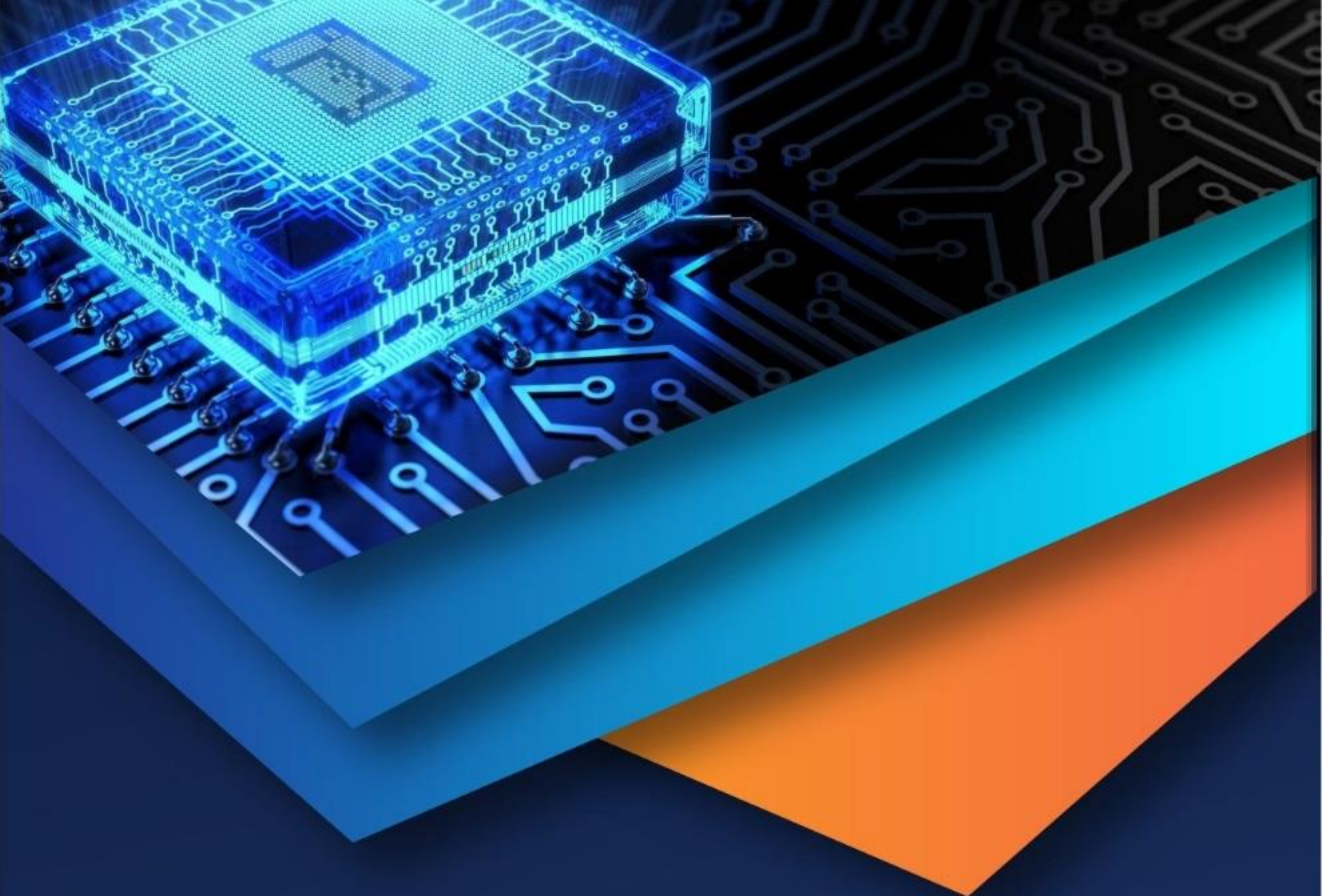
[14] Labille et al. (2005) study the flocculation of colloidal clay by bacterial polysaccharides

[15] Martin (1971) discusses the decomposition and binding action of polysaccharides in soil, while Milas and Rinaudo (1986) analyze the properties of xanthan gum in aqueous solutions.



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