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Experimental Study On The Effect Of Xanthan Gum On Internal Erosion Characteristics Of Erodable Soils

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ABSTRACT

Earth blocks have long been a preferred construction material in rural regions worldwide. There is a growing awareness and need to develop sustainable and environmentally sound alternatives to traditional building materials. The review on enhancing the structural integrity of earthen blocks using the synergy of guar gum and xanthan gum forces on how these biopolymers can improve the mechanical properties of traditional earthen materials. Studies have shown that the optimal concentration of these gums can lead to a notable increase in the durability and longevity of earthen structures, making them more suitable for various environmental conditions. The combination not only contributes to the mechanical properties but also enhances the workability of the earthen mix, allowing for easier construction processes. These amendments aim to improve the soil's workability, strength, and resistance to environmental factors. The paper explores a variety of innovative structural systems that have been proposed in recent years and highlights different systems. Each system represents a unique solution to the challenges of traditional masonry, offering improved structural stability and ease of construction of earthen blocks. This innovation is essential for locations with a high demand for earth block masonry systems, notably earthquake active areas. Given the critical requirement for safe and resilient construction in such areas, the paper investigates the seismic performance of interlocking masonry systems, emphasizing the importance of seismic experiments in determining the safety and reliability of these systems.

Keywords: Interlocking, earthen blocks, biopolymers in construction, seismic masonry, structural integrity of earthen materials, water absorption, durability of earthen blocks, eco friendly.

1 Introduction

Earthen structures are the oldest type of structures used in many engineering projects, mainly in hydraulic projects like dams, levees, channels, and dykes. The purpose of these structures is that they are used to retain water for various purposes such as irrigation, drinking, diversion, flood control, and for generating electrical energy. Locally available materials like soils and rocks of different sizes were used in the construction of these structures. However, there is an inherent risk in these structures. Failure of these structures is usually of low probability but has disastrous consequences such as loss of life. It also leads to high economic and, environmental damages, and causes political and social instabilities. This paper attempts to study the properties of locally available soil and its suitability as a construction material. Gaur gum, which is a natural thickening agent, enhances the viscosity and binding properties of the mixture. Xanthan gum, on the other hand, is known for its excellent stability and ability to retain moisture. When combined, they can significantly improve the compressive strength, flexibility, and water resistance of earthen blocks. Biopolymers, which are naturally produced polymers, exhibit hydraulic and mechanical properties, and have low environmental impact. Therefore, they can be employed as an alternative to conventional civil engineering materials for internal erosion prevention. This study on the potential of using xanthan gum biopolymer for internal erosion control in earthen embankments. Gaur and xanthan gum are both

biopolymers that can enhance the properties of earthen blocks. Gaur gum, derived from the seeds of the cluster bean, and xanthan gum, produced by fermentation of glucose or sucrose, can improve the mechanical properties and durability of earthen construction materials. A synergistic interaction occurs between xanthan gum and galactomannans and results in enhanced viscosity or gelation. This has been extensively studied and has been the subject of numerous articles in the past 40 years. Studies notably reveal the effect of synergy on the rheological properties under different conditions; in particular intrinsic viscosity (Cuvelier, Tonon, & Launay, 1987; Fernandez, 1995; Higiro, Herald, & Alavi, 2006; Launay, Cuvelier, & Martinez-Reyes, 1997), flow behavior (Copetti, Grassi, Lapasin, & Pricl, 1997; Cuvelier et al., 1987; Dea, Morris, Rees, & Welsh, 1977) and viscoelastic properties (Copetti et al., 1997; Fernandez, 1995; Higiro et al., 2006; Mannion et al., 1992; Schorsch, Garnier, & Doublier, 1997) were considered. More recently, investigations focused on the mechanisms to explain the interactions and the molecular associations between both polysaccharides (Grisel, Aguni, Renou, & Malhiac, 2015; Renou, Petibon, Malhiac, & Grisel, 2013; Takemasa & Nishinari, 2016).
We describe herein the rheological behavior, with respect to their synergistic interaction, of a mixture of xanthan and guar gum, the structure of which is the same as that of locust-bean gum, except that the side chains are linked to every other unit19, or two to four units20. However, at relatively high shear rates, the viscosity approaches the value of the more viscous xanthan gum solutions at mass fractions of xanthan gum between 0.1 and 0.15, and the degree of synergy substantially decreases. The transport the solids was enhanced by the cross-linking of guar gum chains using borate ions. In this work, we study the rheology of xanthan gum and guar gum mixtures in simple shear flow and flow through porous media to assess how the synergy in viscosity enhancement extends to complex flows.

1.1 Biopolymer and its types

Polymers that are naturally produced from living matter are referred to as “biopolymers,” which is an abbreviation for the term. The cells of living things are responsible for the production of natural polymers known as biopolymers. In the same way as other types of polymers, biopolymers are constructed from long chains of monomeric building blocks that are covalently bonded together to form larger molecules. The polymers that originate from living organisms, such as plants, animals, or The incorporation of biopolymers in concrete mixtures has been extensively.
1) Compressive Strength Enhancement: Biopolymers can contribute to the improvement of compressive strength in cement concrete. By acting as fillers, they densify the concrete matrix, reducing porosity and enhancing interparticle bonding. This leads to increased compressive strength and improved load-bearing capacity.
2) Flexural Strength Improvement: The addition of biopolymers can enhance the flexural strength of cement concrete. Biopolymers act as reinforcing agents, improving strength of the earthen blocks

2. Related works and methodology

Biopolymers are naturally occurring polysaccharides which have a large number of hydroxyl groups which readily react with water to form long chains of “hydrogels”. On dehydration, the water molecules tend to escape from polymer chains leading to the formation of complexes of linked polymer chains. In addition, during drying, the hydrogels transform from what is termed a “rubbery” to a “glassy” state (Eichler et al. 1997; Ayeldeen et al. 2016). When introduced in soils, biopolymers interact with soil particles and free water in the soil matrix leading to complex networks of polymer chains binding soil particles through hydrogen and/or ionic bonding depending on the intrinsic properties of the biopolymer used (1971; Katzbauer 1998). Though these biopolymers have been previously used in soil stabilization work, only recently it has been suggested as a stabiliser for earthen construction material. Aguilar et al. (2016) and Nakamatsu et al. (2017) stabilised earthen construction material using biopolymers such as chitosan and carrageenan at 3.0 and 2.0% concentrations respectively. In these studies, compressive strength tests were performed on cylindrical specimens of 34mm diameter and 71 mm height, while flexural strengths were obtained from prismatic beam samples of 42 x 44 x 125mm. Mechanical testing was undertaken at 14 days for air cured specimens. Erosional tests were also performed on cylindrical specimens to assess durability. It was reported that the addition of biopolymer led to improved mechanical and durability performance For the treated earthen material. Very recently, the authors here undertook a study to understand the mechanical behaviour of biopolymer treated earthen construction materials (Muguda et al. 2017). In this study, reconstituted soil suiting the requirements of earthen construction was treated with two biopolymers namely guar gum and xanthan gum. Cylindrical specimens (38mm diameter by 76mm height) were tested in unconfined compression, and “bowtie” specimens were tested in tension using the procedure outlined in Stirling et al. (2015). Biopolymer content was added in a range of 0.5-3.0% of dry unamended soil. All the samples were statically compacted to achieve the initial dry density of 19.62 kN/m3 having a porosity of 16.98% and pore void volume of 14.63 cm3 . However, due to the addition of biopolymer there was a slight variation in the initial dry densities achieved and corresponding porosity and pore space volume values. All the samples were left to air dry at a relative humidity of 50% and temperature of 210C and then tested at 7 and 28 days. For comparisons, similar tests were carried on unamended samples and samples with 8% cement. As noted by

Zhao (2014) and Cao et al. (2017), presence of biopolymer has a significant effect on the soil suction so it was imperative to measure suction during the strength tests. Hence, total suction was measured using a WP4C potentiometer for the soil portions remaining after the completion of strength tests. Fig 1 shows the variation of compressive, tensile and suction with varying stabiliser content for both biopolymers. It was observed that the addition of biopolymer at any stabiliser content for both guar gum and xanthan gum increased the suction. However, compared to the 7- day suction, the suction in the guar gum treated specimen at 28 days had reduced, while this was opposite for xanthan treated specimens. Also, it was noted that both biopolymers showed different compressive and tensile strength behaviour. For guar gum, compressive strength increased at 28 days while the tensile strength decreased. In case of xanthan gum, there was a slight reduction in compressive strength, while the tensile strength increased at 28 days. The above differences in the compressive and tensile strengths and suction changes was linked to the soil water-biopolymer interactions which are dependent on the intrinsic properties of the respective biopolymer. As a neutral polysaccharide with large hydroxyl groups, guar gum would form network of hydrogels between soil particles and free water via hydrogen bonding (Chen et al. 2013). At 7 days, these hydrogels (predominantly in a rubbery elastic state) contribute to higher suction. Once these hydrogels transform to a glassy state, the suctions tend to reduce. The increased compressive strength at 28 days is therefore attributed to the network of hydrogels in a glassy state. As a chemically weaker bond, the hydrogen bonding may not contribute much to tensile strengths. Xanthan gum is an anionic polysaccharide which will have ionic bonding with soil particles in addition to hydrogen bonds (Chen et al. 2013). Similar to guar gum, at 7 days, the combination of suction and hydrogel bonding appears to contribute to both compressive and tensile behaviour of xanthan treated soils. However, unlike guar gum, the ionic bonding of hydrogels appears to contribute to the increased suction and tensile strengths at 28 days. The above understanding gives an insight on the mechanical behaviour of biopolymer treated earthen construction materials. With this insight of the variation of strength and suction at different biopolymer dosages, the study is furthered here to understand the effect of biopolymer on the durability of treated earthen construction material Erodable soils are usually vulnerable to erosion and transported by running water. They can be dispersive soils that lose their cohesive ability as they encounter with pure water, or non-cohesive silt and very fine sands that have little stability to withstand the water's force. Dispersive soils are susceptible to displacement when subjected to clear water and are vulnerable to erosion. The willingness against dispersive erosion depends on many factors such as clay mineralogy and salt dissolved in pore water and eroding water. As dispersive clay is submerged in water, the clay grains tend to separate into particles due to increasing repulsive force causing a significant reduction in the bond strength of the inter-particles. This implies they can indeed be rapidly dissociated even under a very gentle hydraulic gradient by flowing water. Soils like non-cohesive silt and very fine sands have a great risk of erosion by water due to the absence of cohesive bonds between the soil grains. Their intake and subsequent transfer are regulated by the body-weighting of the particle size. Soils that contain a high percentage of fine sand and silt, such as silty sand, sand, water deposits, and man-made mound soils, will be extremely eroding This chapter discusses earlier work contributing to soil erosion and soil treatment with chemical additives. It involves studies performed to evaluate factors influencing soil erosion, the behaviour of erodable and dispersive soils stabilized with conventional chemical additives, the effectivenessof Xanthan Gum Biopolymer additive for soil improvement.

2.1 DISPERSIVE SOILS

Dispersive soils are described as the soils which, when they come in contact with the pure or still water, these soils certainly break down into induvial particles under suspension. Dispersion takes place in such soils where the clay particles have more repulsive forces than the attractive forces when these soils are in a saturated condition. This phenomenon is caused due to the reduction in cation concentration in pore water, resulting in the disintegration or deflocculating of soil particles. It is for that reason; these soils undergo suspension the repulsive forces generate and disintegrate the soil particles. Soils composed of clay minerals which will possess high exchangeable sodium ion concentrations are commonly vulnerable to dispersion. These types of soils might as well be extremely sensitive to erosion and consequently, gives rise to the formation of gullies in those soils. Dispersive soils are also recognized in the field by identifying the existence of gullies and subsurface erosion tunnels. According to Brink soils that have high quantities of Exchangeable Sodium Percentages (ESP), and the soils in which it has a clay mineral mainly consist of smectite mineral group such as montmorillonite. However, some other clay minerals called Illites and kaolinite with high ESP values are also reported as highly dispersive soils and have dispersive characteristics in its inherent structure.

2.2 CHARACTERISTICS OF DISPERSIVE SOILS.

Prior works in identifying the dispersive characteristics of soils have been executed by several researchers and conclusions are drawn . This work consists of the identification of a variety of soil properties like soil fabric arrangement, soil mineralogy, soil geochemistry, soil consistency, and grain size distribution and afterwards determines any kind of relations that help to assess the dispersive characteristics of those soils. 2.2.1 Fabric The fabric of a given soil is mainly contingent upon the soil mineralogy, grain size distribution of soil, and the shape of the specific grains that the soil consists of. Weathering and its formation also play an important role in the formation of fabrics in the soils. Walker assessed the dispersive soil under Scanning

Electronic Microscopy (SEM) and saw two types of soil fabrics, primarily as clay and secondary as sand and the silt mixture acting as clay matrix. Clay particles are closely packed 14 by face-to-face bonding called as "turbostratic" fabric. in which the clay forms a small network to interconnect the evenly shaped pores continuously, on the other hand, silt and sand are evenly distributed over the clay matrix. Soils that have high ESP values have more swelling and have a more dispersive nature when compare to low ESP soils. in dispersive soils, the clay particles move into their surrounding void spaces and reduce the pore spaces. In general, open fabric, size is less than 30µm for dispersive soils and less than 50µm for non-dispersive soils. the pore spaces of clay particles in dispersive soils are generally in a range somewhere between 2 µm to 10 µm. Bell & Walker furthermore mentioned that the soil fabric changes with Total Dissolved Solids (TDS) levels, higher TDS concentration has a granular fabric, whereas low TDS concentrations have a turbostratic fabric. It has been observed that the variation of pore spaces also depends on TDS concentration. as high TDS level has larger pore space when compared to low TDS level.

2.3 IDENTIFICATION OF DISPERSIVE SOILS

Expertise has shown that conventional index tests like particle size distribution, Atterberg limits, or compaction characteristics cannot distinguish between dispersive soils and non-dispersive soils. It should always be noted that not every material in the field which exhibits erosion gullies and funneling are inherently dispersive. The materials could only be highly erodable (low cohesion) or prone to slaking, which would require different construction techniques and/or material treatments [41]. Therefore, the dispersive characteristics must be detected positively by conducting various specialized tests on soil samples. There are currently four methods commonly used in laboratory tests to identify dispersive soils. These tests include the Pinhole Test. the Double Hydrometer Test, the Crumb Test and various soil chemical analyses, and usually a combination of the findings acquired from these processes, is being used to evaluate the dispersive potential of soils.

2.4 PROBLEMS ASSOCIATED WITH DISPERSIVE SOILS Dispersive erosion does have the capacity to become a significant threat to engineering projects. Soil erosion tends to cause attributes such as gullies, dongas, and pipes get formed. Dispersive soils employed in the construction of embankment dams were indeed likely to develop pipe structures unless properly identified and wisely handled, which could result in dam failure. As they have low permeability and therefore low infiltration rates, the presence of dispersive soils also poses a challenge for agricultural purposes. Brink, stated that dispersive soils are common in many parts of South Africa, and categories into 4 types, most of which are consistent with some of those described below:

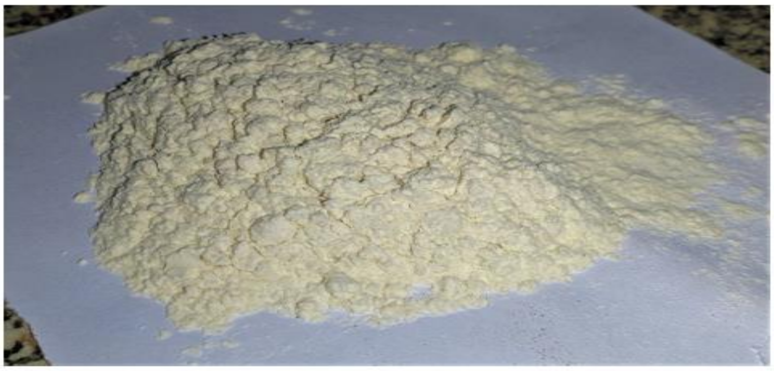
- In low lying areas where inlet water does have high Sodium Absorption Ratio (SAR) value especially in vulnerable locations where the climatic N- values for winters range from 2 to 10. Soils obtained from granitic rocks are more likely to develop high Exchangeable Sodium Percentage (ESP) values and therefore become dispersive. These weathered rocks contain a primary mineral as albite, orthoclase, and muscovite which contain low Ca^{2+} and Mg^{2+} ion concentrations and thus promote the SAR values.
- In places where a transported soil's parent material contains large amounts of illite and some other 2:1 clay which has a high value of ESP. This conforms to the upper Beaufort group's Cretaceous mud-rocks and the Karoo Supergroup's Molteno Formation, during which climatic N-values fall in between 2 and 10. Soils of these formations are almost always dispersive in low lying areas.
- In arid areas, where the N-values exceed 10 despite the high SAR values within the saturation extract, though free salts limit the development of dispersive properties, dispersive soils may develop if free salts are leached.
- Soils derived from granite or mud-rocks from many parts show dispersive features even if the ESP values are below 5. That is most probably because of the heavy proportion of Mg^{2+} compared with Ca^{2+}

2.4.1 Piping Failures associated with Dispersive Soils in Earthen Dams The concentrated leakage on the downstream side is caused by water flowing through the soil pores in the conventional description of the piping failure in an earth dam. The erosion generally starts at the end of the leak discharge triggering a local concentration of the seepage forces and erosion happens. The erosion then goes upward and establishing a tunnel-shaped entry or pipe until it eventually hits the water source. Rapid failure would have occurred within the dam by this time. This mode of failure usually occurs in cohesionless soils that have very little resistance to the erosive forces of percolating water once conduits have been formed by the dispersion of clays. Apart from erosion caused by the lack of cohesive bonds in the soil, erosion in dispersive soils doesn't happen as a result of seepage forces through the soil pores. These clays may disperse in static water. Piping in dispersive soils seems to be due to a process of deflocculating, where water moves via a leakage stream and material loss from a certain seepage channel occurs simultaneously across its total duration. There must always be a concentrated leak for initiating erosion and the leakage channels are generally cracked or are in the fissures within the soil.The primary factor controlling the soil's susceptibility towards dispersive piping is the presence of sodium cations in the clay surface compared to other cations. Another significant element is that of total dissolved salts (TDS) concentration in the pore water. The lower the pore water's TDS, the greater the susceptibility of the saturated sodium clays to repel each other and they by contributing to dispersion. Piping indications in earth dams take the shape of tiny leaks of muddy coloured water from the earthen embankment after the reservoir has been initially filled. According to Bell & Maud, most earth dam failures in South Africa occurred while the dam was first wetted and filled. Pipes are rapidly enlarged leading to structural failure.

3 MATERIALS AND RESULTS

3.1 Xanthan gum

Xanthan Gum is a polysaccharide frequently used as an additive in various foods to increase the viscosity and used as rheology converters, which is produced by glucose fermentation, or it is sucrose of bacterium called Xanthomonas campestris [98-99]. Xanthan Gum is mainly composed of D-glucuronic acid, D-mannose, propylated mannose, 6-O-acetyl D-mannose, and a 1,4- linked glucan [100]. The redefined chemical formula of Xanthan Gum is $C_{35}H_{49}O_{29}$. The best-known property of Xanthan Gum is its pseudoplastic nature, i.e., degradation of viscosity depends on an increase in the shear rates. While in static conditions, the addition of a small quantity of Xanthan Gum (0.5%) brings a high rise in viscosity. Besides, unlike with other gums, Xanthan Gum gives high stability over various pH and temperatures. Moreover, the interaction of Xanthan Gum with polysaccharides such as glucose, mannose ($C_6H_{12}O_6$), potassium gluconate ($C_6H_{11}KO_7$), acetate (CH_3CO_2), and pyruvate (CH_3-CO-COOH), forms hydrophilic colloids.



Collected Xanthan Gum Additive

Materials The soil mixture used in the previous study (Muguda et al. 2017) was used herein comprising 20% Kaolin, 70% sharp sand and 10% gravel by mass. This soil mix complies with the requirements for earthen construction materials given in the literature (e.g. Oliver & Mesbah 1987; Houben & Guillaud 1994) and is a combination widely investigated in earthen construction. Atterberg limits and compaction characteristics (using the 2.5kg Proctor test) obtained in accordance with British Standards (BS 1377-2 1990; BS 1337-4 1990) for the unamended soil mixture are given in Table 1. Commercially available guar gum and xanthan gum were chosen as biopolymer stabilisers in this study.

Table 1. Physical properties of the unamended soil mixture in this study

Index property	
Standard compaction tests	
Maximum dry density (kg/m3)	1870
Optimum moisture content (%)	9.8
Grain size distribution	
Gravel content (%)	10
Sand content(%)	70
Silt content (≤ 63 μm, %)	04
Clay content (≤ 2 μm, %)	16
Atterberg limits	
Plastic limit (%)	36
Liquid limit(%)	18
Plasticity index (%)	

3.2 Experimental Programme In order to understand the durability properties of the treated biopolymer treated materials, two recognized durability tests, namely the "Geelong" Test (erosion test) as per New Zealand earthen construction (NZS 4298 1998) and the "Immersion" test as per German code (DIN 18945 2013) were chosen for this study.

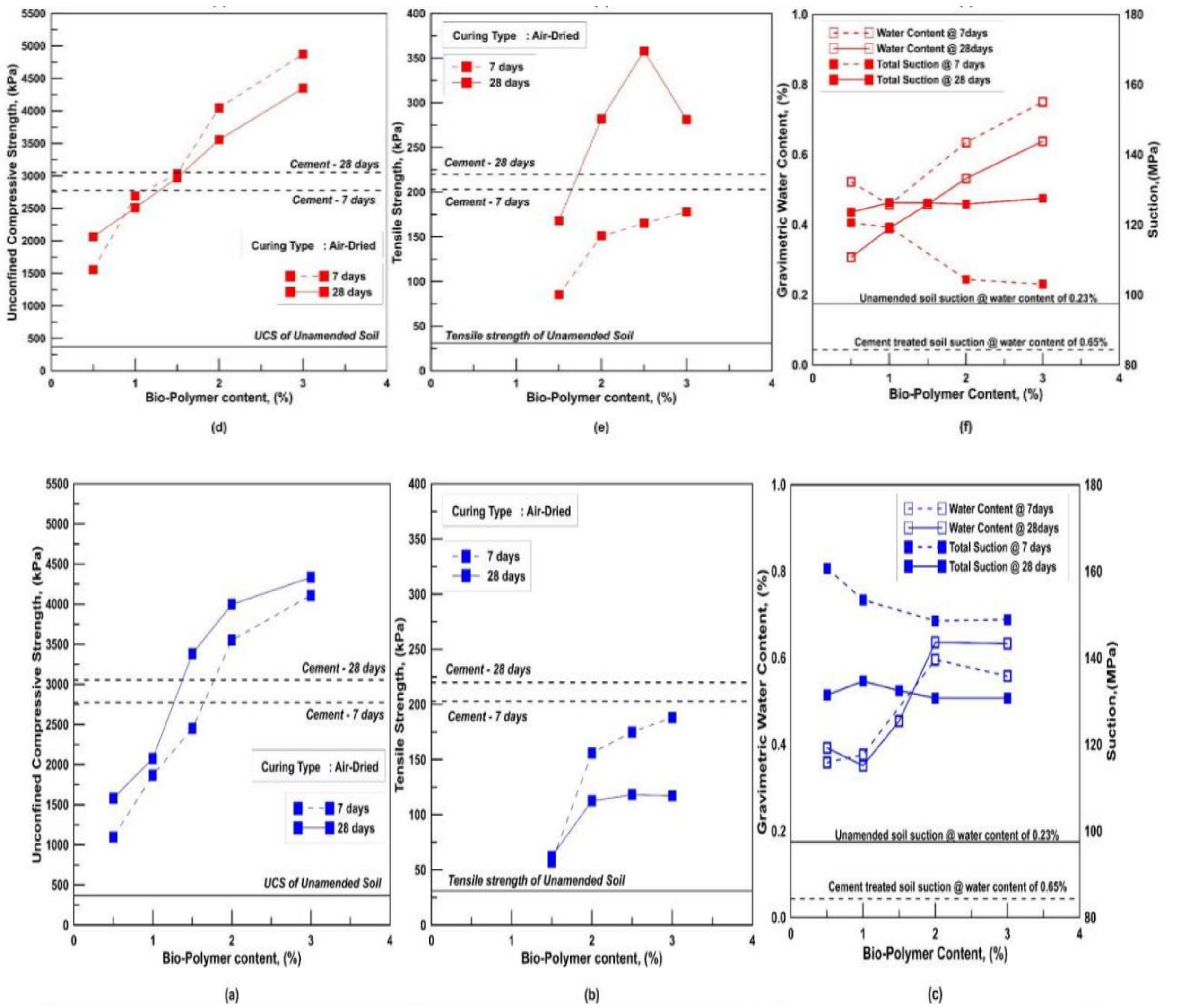


Figure 1. Variation of compressive strength, tensile strength, total suction and water content with different biopolymer content for both the biopolymers. Guar Gum (Fig 1a to 1c) and Xanthan gum (1d to 1f) (As per Muguda et al. 2017

3.2.1 Geelong tests It can be noted from Fig 1a and 1d, that for both the biopolymers, the compressive strengths of samples treated at 1.5% stabiliser content achieved similar strengths of 8% cement treated samples, indicating about 1.5% stabiliser content is enough to match the performance of 8% cement. Hence, for the Geelong tests, earthen cubes of 150mm stabilised with 1.5% of biopolymer content formed the test samples. All the ingredients were dry mixed initially and later water as added and mixed thoroughly for 10-15 mins. The bulk soil mix was then divided into three equal parts and introduced to the mould one part at a time. Using a vibratory hammer, each layer was compacted to the required density. These steps were repeated for all the three portions. All blocks were compacted

4 EFFECT OF XANTHAN GUM ON THE PROPERTIES OF VARIOUS SOILS

4.1.1 Compaction Characterization The compaction test plays a significant role in strengthening base and subbase layers of soil, in which the soil is compacted to a required density after mixing with a stabilizing material. The density obtained after the Proctor compaction test will affect shear strength, settlement, and bearing capacity of soils. Therefore, it is crucial to examine the compaction behaviour of various soils mixed with different Xanthan Gum concentrations (0.5, 1, 1.5, and 2%). From the results, it was observed that the Maximum dry unit weight (MDU) decreased, and Optimum Moisture Content (OMC) increased with an increase in Xanthan Gum concentration from 0.5 to 2.5% as shown in Figure (4.1- 4.4). Figure 4.1 shows the compaction characteristics of Xanthan Gum treated clayey soils. As the concentration of Xanthan Gum increases, MDU of clayey soil decreased from 16 to 13.7 kN/m3, and OMC increases from 32 to 37.3%, respectively. Figure 4.2 shows the compaction characterizes of Xanthan Gum treated silty soils, the same trend was observed. As Xanthan Gum content increases the OMC of treated soil increased and decrement is shown in MDU values, the same pattern is perceived by other researchers.

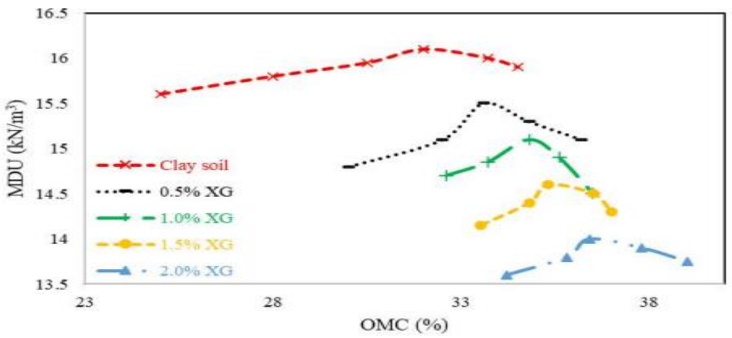


Figure 4.1: Compaction Characteristics of Xanthan Gum treated soil at various concentrations

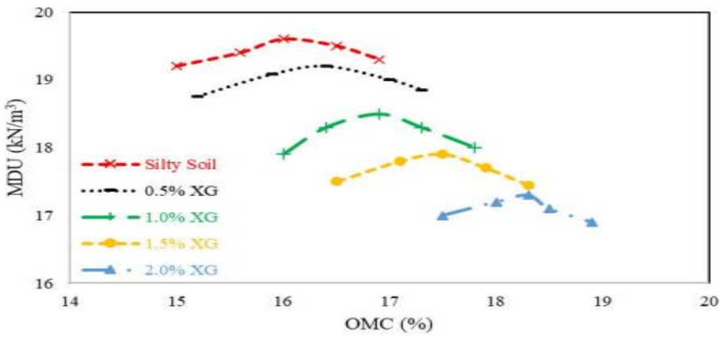


Figure 4.2: Compaction Characteristics of Xanthan Gum treated silty soil at various concentrations

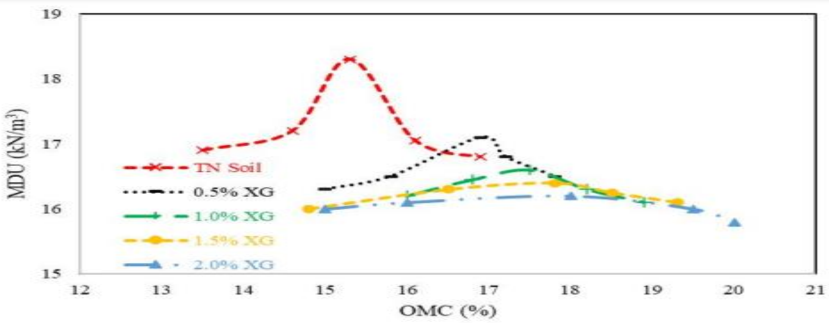


Figure 4.3: Compaction Characteristics of Xanthan Gum treated TN sample at various concentrations

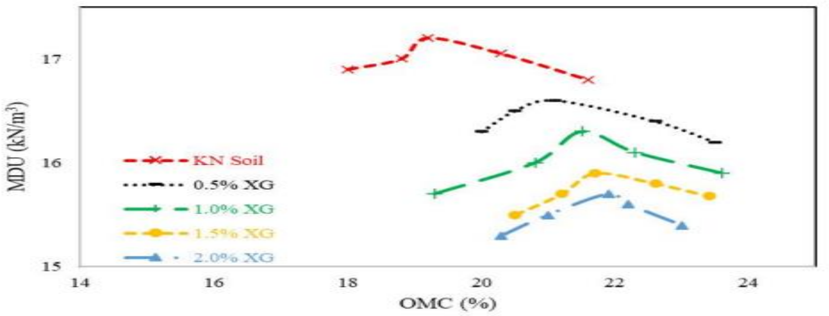


Figure 4.4: Compaction Characteristics of Xanthan Gum treated KN Sample at various concentrations

A similar trend was observed for Xanthan Gum treated Dispersive clays (KN sample) and Dispersive silt (TN sample) MDU was decreased from 18.2 to 16.1 and 17.1 to 15.8 kN/m3 with an increase in Xanthan Gum contents. Raise in OMC values were observed from 15.3 to 18% for the TN sample and 19.2 to 21.8% for the KN sample shown in Figure (4.3 - 4.4). Because of Xanthan Gum's rheology qualities, the variance in the maximum dry unit weight of the treated soils seems to depend on the variety of soil with which Xanthan Gum is mixed. The decrement in MDU values in Xanthan Gum mixed soil is due to the viscous nature of Xanthan Gum, where the soil grains are discrete randomly due to its lightweight, which results in a reduced density of Xanthan Gum mixed soil. As Xanthan Gum content increased, the OMC is also increased, this is due to the water absorption capacity of the biopolymer.

4.1.2 Effect of Xanthan Gum on Unconfined Compressive Strength.

The UCS strength of soils plays a vital role in geotechnical engineering works, as it needs actual characterization to measure the appropriateness of soil for construction. Even though the UCS values can't help in interpreting the bearing capacity in the field, but it can help in knowing the performance of shear strength with the variation of Xanthan Gum additive.

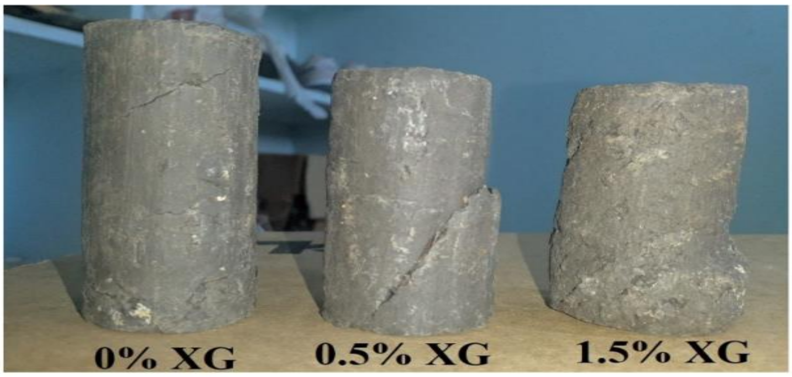


Figure 4.7: Failure Patterns of Xanthan Gum treated clayey soils.

As Xanthan Gum content increases from 0.5 to 2% the UCS value of treated clayey soil increased for all combinations for the initial 28 days. As curing days increase, the UCS value of treated clay increased, at a slower rate as shown in figure 4.5. From Figure 4.5 it is evident that 1% Xanthan Gum performs better compare to Xanthan Gum combinations for longer curing periods. Lower Xanthan Gum content soil has less strain as compared to higher Xanthan Gum contents, as shown in Figure 4.6. Figure 4.6 shows the stress-strain curve for Xanthan Gum treated clayey soils for 28-day curing periods; as Xanthan Gum content increases, the ratio of strain increases it is due to the viscous nature of Xanthan Gum, which holds the clay particles tight from shear failure and these combinations have more plasticity when compared to lesser Xanthan Gum concentrations. Figure 4.7 shows the failure pattern of Xanthan Gum treated clayey soils for various Xanthan Gum concentrations. Whereas Figure 4.7 shows the shear failure for 0.5% addition of Xanthan Gum as concentrations increase the soil fails by buckling at higher strains. This is the reason for the change in height in UCS samples.

5. CONCLUSIONS

The performance of Xanthan Gum on various soils (clay, silt, and dispersive soils) shows more significant potential in the improvement of soil. The following conclusions were drawn from the preliminary investigations.

- The addition of Xanthan Gum to various soils decreases the Maximum Dry Unit Weight (MDU) values and increases Optimum Moisture Content (OMC) values for all Xanthan Gum combinations. These changes in OMC and MDU varies from soil to soil.
- The addition of Xanthan Gum to soil increases its Unconfined Compressive Strength (UCS) for all curing periods. The UCS values of the stabilized specimens show the most significant changes during the initial 28 days curing period, and a minor increase was observed after 28 days up to 360 days.
- From the results, it is understood that the UCS values increase significantly up to 1% addition of Xanthan Gum to the soil, further the rate of increment is low. Hence 1% is considered as optimum content.
- One-dimensional tests show that an increase in Xanthan Gum concentration.
- It is observed that the addition of Xanthan Gum reduces the coefficient of permeability of Xanthan Gum treated soils.
- The addition of Xanthan Gum to Dispersive soils (TN and KN samples) reduces the Percentage Sodium and Sodium Adsorbed Ratio.

➢ From the crumb test, the addition of 1% Xanthan Gum to soils, changes its dispersive nature. Similar results were observed by the Double Hydrometer Test and Cylindrical Dispersion Tests also.
➢ From the pinhole test, it is observed that the erosion resistance increases for dispersive soils treated with Xanthan Gum. As the Xanthan Gum concentration increases, the soil resistance towards erosion increases for both samples, and changes its nature from highly dispersive (D1) to non-dispersive (ND2) for KN sample and dispersive (D2) to non-dispersive (ND1) for TN sample soil at 1%Xanthan Gum.
➢ From the degradation test, higher resistance is offered by the soil matrix upon alternate wetting and drying cycles. The observed change in weight due to the alternate wetting and drying cycles at 1% Xanthan Gum content is less than the permissible limit (14%) for all soils.
➢ The results from the Hole Erosion Test demonstrates that the Erosion Rate changes linearly with the Hydraulic Shear Stress for all Xanthan Gum treated soils.
➢ It is evident that the rise in Xanthan Gum concentration reduces the erosion rate, and increases the hydraulic shear stress of treated soils. It was also observed that as curing days increase erosion rate decreases and allows the soil to resist higher hydraulic heads.
➢ Based on the background study and the tests undertaken in this study, it can be concluded that the addition of biopolymers has a significant effect on suction and mechanical behaviour of earthen construction materials which can be regarded as manufactured unsaturated soils. The strengths of the biopolymer treated materials appears to be linked to a combination of suction and hydrogel bonding. The durability tests suggest that xanthan gum performs satisfactorily in both erosional and immersion tests, while guar gum performs satisfactorily only in erosional tests. The initial XRCT scans could not capture the hydrogels at both the curing periods. However, it was noted that there was slight rearrangement of soil particles between 7 and 28 days. This rearrangement was more evident in guar gum treated specimens.

6 RECOMMENDATIONS FOR FUTURE STUDY:

➢ The current study focused on erosion through cracks only. Therefore, a further comprehensive study can be done on internal erosion with all other possible causes. In future, soil – water – electric – electrolyte theories and DLVO theories can be studied to explain the dispersion phenomenon.
➢ The study can also be extended for commercial soils with the appropriate proportions, and various erodable soils with fine and coarse particles.
➢ Investigating the impacts of in-situ mixing procedures with larger hydraulic gradients may be studied.
➢ The study can further proceed by performing other testing approaches for soil erodibility.
➢ Further laboratory testing along with pilot field studies is recommended

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