ACTA TECHNICA JAURINENSIS
Vol. XX, No. Y, pp. ZZ-ZZ, 2024
10.14513/actatechjaur.00748

Research Article

Application of Gum Arabic on the Geotechnical Properties of Subgrade Materials

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Submitted: 14/08/2024 Accepted: 16/09/2024 Published online: 01/10/2024

Abstract: This study investigates the impact of Gum Arabic on the geotechnical properties of subgrade soil materials, a non-traditional soil stabilization technique. Given the need for sustainable and locally available alternatives in road construction, the study aims to assess how different percentages of Gum Arabic affect the physical and mechanical behavior of soil. The research aims to provide sustainable and locally available alternatives in road construction. Three soil samples were treated with varying percentages of Gum Arabic, (1.5%, 3%, 6% and 12%), and standard geotechnical tests were conducted under both soaked and unsoaked conditions. The results showed that the average natural moisture content of the soils was 7.9%, 2.2%, and 4.6%. The addition of Gum Arabic increased the peak maximum dry density of the soil samples by 8.02%, 1.88, and 7.88%. The maximum unsoaked California Bearing Ratio (CBR) values of soil samples were 32.1%, 81.7%, and 48.7%, respectively. Whereas, maximum soaked CBR values of soils S1, S2 and S3 obtained at 1.5%, 6% and 1.5% additions of gum Arabic were 8.4%, 28.7% and 16.9% respectively. The study recommends using 3% Gum Arabic to improve the CBR property of soil samples. The application of Gum Arabic showed significant improvements in soil behavior under both soaked and unsoaked conditions.

Keywords: Gum Arabic; Subgrade; Road Construction; Soil stabilization; geotechnical properties; CBR

I. INTRODUCTION

As infrastructure development expands globally, especially in regions with limited access to conventional construction materials, there is a pressing need to explore alternative materials that are both cost-effective and environmentally friendly. Alternative materials like expansive clay can offer cost-effective solutions, especially in regions where conventional materials are scarce or expensive [1]. By utilizing locally available materials like expansive clay, construction costs can be reduced, making infrastructure development more affordable [2]. However, expansive clay, known for its high shrink-swell potential, can cause significant damage to structures if not managed properly. Expansive soils are always troublesome to employ as a construction material for roads, due to their significant volume expansion caused by water [3]. This expansion can lead to significant damage to structures and infrastructure, including roads, buildings, and bridges. It has always been difficult to build pavements over subgrades of expansive and soft soil as a result of the limited bearing capacity and severe swelling characteristics of these soils.

The use of Gum Arabic in geotechnical engineering has gained significant attention in recent years due to its potential benefits in improving the properties of subgrade materials. This natural biopolymer has been shown to enhance the stability, strength, and durability of soil, making it a promising additive for geotechnical applications [4]. Gum Arabic, a natural exudate obtained from Acacia trees, has been found to have unique properties that can enhance the strength and stability of subgrade soils. One of the key advantages of Gum Arabic is its ability to increase the cohesion and plasticity of soils, leading to improved compaction and stability. This can be particularly beneficial in areas with poor soil conditions, where traditional stabilization methods may not be effective. By adding Gum Arabic to subgrade materials, engineers can achieve higher strength and better performance in terms of load-bearing capacity and settlement control. In addition to its mechanical properties, Gum Arabic has also been found to have a positive impact on the hydraulic conductivity of soils. By forming a film around soil particles, Gum Arabic can reduce water infiltration and improve drainage, leading to better overall performance of the subgrade materials [5]. Furthermore, Gum Arabic is a sustainable and environmentally friendly alternative to chemical stabilizers commonly used in geotechnical engineering. Its natural origin and biodegradability make it a preferred choice for projects that prioritize environmental sustainability.

Subgrade materials, which are essential for the stability and longevity of roads, often require enhancement to meet engineering standards. Subgrade materials must meet specific engineering standards to ensure the stability and longevity of roads [4]. The subgrade layer in road construction is critical for providing structural support to the pavement. Its properties directly impact the overall durability and performance of the road. Problematic subgrade soils like expansive clays, peat, and marine clay can cause significant issues for road construction [4]. These soils have undesirable engineering qualities like inadequate strength, overbearing consolidation, and volume fluctuations with moisture content. Expansive clays, in particular, can undergo substantial swelling and shrinking with moisture fluctuations, leading to severe structural damage and reduced bearing capacity. However, with appropriate stabilization methods, such as lime or cement treatment, its negative effects can be mitigated, making it a viable construction material [1].

Traditional methods of subgrade stabilization often rely on costly and sometimes environmentally harmful materials such as cement and synthetic polymers [6]. These materials are commonly used because they tend to enhance the engineering properties of subgrade soils, such as strength, stiffness, and drainage. However, their use can have significant environmental and economic impacts [7, 8]. Traditional stabilization techniques often involve the use of lime, cement, or chemicals which improve soil properties by enhancing strength, reducing compressibility, and minimizing volume changes [9]. However, these methods can be costly and environmentally taxing, especially in regions where these materials are not readily available. The increasing costs and environmental concerns associated with conventional subgrade stabilization methods necessitate the exploration of alternative materials that are both effective and sustainable. Traditional stabilizers such as cement, lime, and synthetic polymers, while effective, contribute to high construction costs and significant environmental impacts due to their production processes and long-term degradation [10].

Given the high expense of conventional building materials, there is a growing need to explore cost-effective and environmentally friendly alternatives. Utilizing locally available materials, such as expansive clay, can reduce construction costs and make infrastructure development more affordable [2]. However, innovative stabilization methods are required to address the inherent issues associated with these soils. Gum Arabic, a natural polysaccharide derived from the sap of Acacia trees, has long been valued for its versatility and utility in various industries, including food, pharmaceuticals, and textiles [11, 12]. Recently, there has been growing interest in its potential applications in geotechnical engineering [13]. Gum Arabic, derived from the sap of Acacia trees, offers a biodegradable and sustainable solution for soil stabilization. Its potential to enhance the geotechnical properties of expansive clays and other problematic soils is explored, aiming to improve their strength, stability, and resistance to moisture-induced volume changes. Gum Arabic offers a natural, biodegradable alternative that can enhance soil strength, reduce compressibility, and improve stability against moisture changes [11, 13]. Gum Arabic, with its unique chemical properties, presents a promising solution for improving the geotechnical properties of subgrade materials used in road construction and other foundational infrastructure projects.

The use of natural materials in geotechnical engineering has gained significant attention in recent years. [14] investigated the use of precipitated silica from rice husk to improve the properties of black cotton soil. The study included various tests to evaluate the plasticity, strength, permeability, and compressibility characteristics of the treated soil samples. Similarly, [15] examined the geotechnical properties of drinking water sludge blended with crushed concrete and incineration ash for road subgrade suitability. Laboratory tests were conducted to assess compaction, California bearing ratio, undrained triaxial compression, and consolidation of the materials. In the realm of material science, [16] explored the application of cashew tree gum on the production and stability of spray-dried fish oil. The study focused on the physical and thermal properties of the fish oil with different carbohydrates as carriers. Additionally, [17] investigated the influence of modified starches as wall materials on the properties of spray-dried lemongrass oil. The study found that oil retention increased when gum arabic was partially replaced by OSA-starch. Furthermore, the synthesis and characterization of chitosan/gum arabic nanoparticles for bone regeneration were studied by [18]. The scanning electron microscopy study revealed the structure of the nanoparticles, highlighting the potential application of these materials in biomedical fields. Additionally, [5] described gum arabic as a multi-functional binder for the fabrication of NiFe2O4 nanotube electrodes, showcasing its potential in lithium-ion and sodium-ion batteries. While the literature primarily focuses on the application of natural materials in various fields, such as geotechnical engineering and material science, there is a gap in research regarding the specific application of gum arabic on the geotechnical properties of subgrade materials. [19] conducted an experimental study on the potential suitability of natural lime and waste ceramic dust in modifying the properties of highly plastic clay, indicating the importance of exploring natural materials for soil stabilization. This highlights the need for further research on the application of gum arabic in enhancing the geotechnical properties of subgrade materials.

In the engineering discipline, the stability and durability of road pavements are heavily influenced by the geotechnical properties of subgrade materials. Subgrade performance, which includes strength, compressibility, and permeability, plays a crucial role in the longevity and safety of transportation infrastructure. Traditional methods of improving subgrade properties often involve chemical stabilization using lime, cement, or other additives, which can be expensive, environmentally taxing, and sometimes ineffective in specific soil conditions. In many developing regions, especially in areas with limited access to conventional stabilizing agents, there is a growing need for alternative, sustainable, and cost-effective materials to enhance subgrade performance. Gum Arabic, a natural polysaccharide, has shown potential in various industrial applications due to its adhesive properties, but its potential as a stabilizing agent in geotechnical engineering remains underexplored. The lack of comprehensive studies on the impact of Gum Arabic on the geotechnical properties of subgrade materials poses a challenge to understanding its effectiveness, optimal usage, and long-term benefits in road construction.

This research seeks to investigate the efficacy of Gum Arabic in improving the geotechnical properties of subgrade materials, potentially offering a sustainable and economical option for infrastructure development. The objective of this study is to investigate the effects of Gum Arabic on the geotechnical properties of subgrade materials, including soil strength, compaction characteristics, permeability, and durability. This research will also contribute to the scientific basis for the application of Gum Arabic as a viable alternative for subgrade stabilization, particularly in regions where traditional stabilizers are not feasible.

II. Methodology

Three soil samples (clay, sandy and the combination of clay and sandy soil) were obtained. These soil samples are represented by S1, S2, and S3. With S1, S2, and S3, representing clay, sandy, and the combination of the clay and the sandy soils in the ratio 1:1 respectively Gum Arabic in percentages of 1.5%, 3%, 6%, and 12% of the soils weight is added to the soil, the properties of the soils will be determined to appraise the influence of the different additions of Gum Arabic to the soils. The gum arabic used and mix ratio of formulation used are shown in **Fig. 1** and **Table 1** respectively.

Figure 1. Gum arabic

Table 1. Mix ratio formulation of soil samples

Gum Arabic (%)	*Clayey soil (g)*	*Sandy soil (g)*	*Mixture of the two sample (g)*
1.5	4925	4925	4925
3.0	4850	4850	4850
5.0	4700	4700	4700
12.0	4400	4400	4400

The tests employed in this research includes, Moisture Content Test, Specific Gravity Test, Particle Size Distribution Test, Atterberg Limit Test, Compaction Test (British Standard Light) and California Bearing Ratio Test (CBR). The tests' citations noting the standard procedure to be followed in performing all the listed tests are presented in **Table 2**.

1. Specific Gravity Test

The density bottle, was dried at a temperature of 105°C, cooled in a desiccator and weighed to the nearest 0.001g (W_1). Oven-dried soil sample was poured into the bottle, and mass of bottle + soil was noted (W_2). Distilled water was poured into the bottle, and the soil sample was left to soak for a period of 2 to 3 hours to become completely saturated. Water was added to fill the bottle to about half its capacity. To remove entrapped air, the density bottle with its stopper removed was heated on a water bath. The soil inside the density bottle was gently stirred with a clean glass rod, and any adhering particles were carefully washed off from the rod with a few drops of distilled water to prevent loss of soil particles. This process was repeated until no more air bubbles were observed in the soil-water mixture. The temperature inside the bottle was carefully observed and recorded. The stopper was then inserted into the density bottle, wiped clean, and weighed (W_3). Subsequently, the bottle was emptied, thoroughly cleaned, and filled with distilled water at the same temperature. The stopper was inserted into the bottle, wiped dry on the outside, and then weighed (W_4). Three observations were recorded for the same soil using this procedure.

$$G = \frac{(W_2 - W_1)}{(W_4 - W_1) - (W_3 - W_2)} \quad (1)$$

2. Moisture Content Analysis

Using the pycnometer method, the pycnometer was washed, cleaned, and dried. The pycnometer along with its brass cap and washer, was weighed to an accuracy of 1g and recorded as (W1). A wet soil specimen weighing between 200g to 400g was then placed into the pycnometer and weighed with its cap and washer (M2). Water was filled into the pycnometer containing the wet soil specimen to approximately half its height. The mixture was thoroughly stirred using a glass rod, and additional water was added and stirred until the pycnometer was filled with water, flushing through the hole in the conical cap. Subsequently, the pycnometer was dried externally and weighed (M3). Afterwards, the pycnometer was emptied, meticulously cleaned, filled with water, and weighed again after flushing through the hole in the conical cap (M4). The moisture content was calculated using Eq. (2).

$$W = \frac{M_2 - M_1}{M_3 - M_4} \cdot \left[\frac{G-1}{G} - 1\right] \cdot 100 \quad (2)$$

where M_1, M_2, M_3, and M_4 represent the respective masses as described in the procedure for determining moisture content using the pycnometer, and G denotes the specific gravity of the soil solid.

3. Atterberg Limit Test (Liquid Limit Test)

By undoing the two top screws and utilizing a gauge or the grooving tool's handle, the liquid limit device's cup's drop was adjusted. The drop was precisely set to 1 cm at the base's point of contact, and the screws were tightened after adjustment. Approximately 120g of the air-dried soil sample passing through a 425 micron IS sieve was taken. A consistent mix was achieved by thoroughly mixing the soil sample with distilled water in an evaporating dish or glass plate for about 15 to 30 minutes. The mixture was then kept under humid conditions to ensure uniform moisture distribution for a sufficient amount of time, with some fat clays requiring up to 24 hours of maturing time.

A part of the dried paste was removed and properly mixed again. After that, a spatula was used to insert it inside the device's cup, and a straight edge or spatula was used to level it so that the maximum thickness point had a minimum soil depth of 1 cm. The evaporating dish was used to hold any extra dirt. Using the proper instrument, a groove was carved in the sample inside the cup. With the tool held perpendicular to the cup, the grooving tool was pulled through the paste in the cup along the symmetrical axis, that is, along the diameter through the cup's center line. The device's handle was rotated at a speed of two revolutions per second, and the number of blows was tallied until the soil specimen's two halves made contact at the bottom of the groove over a distance of 12 mm as a result of flow rather than sliding. Then, using a spatula width-wise from one edge to the other of the soil cake, perpendicular to the groove, a representative sample of the soil was taken. This includes the area of the groove where the dirt filled it in and sealed it. After being taken out of the cup, the soil residue was combined with the dirt that remained in the evaporating dish.

In order to change the water content of the mix in the evaporating dish, either more water was added or the soil was kneaded if the desired water content was to be lower. Dry soil was not added to reduce the water content in any case. The process was repeated to determine the water volume (w) and the number of blows (N) in each sample. A flow curve between log N and w was drawn, and the liquid limit was determined based on the analysis.

Table 2. *Test citation*

Serial Numbers	Tests	Methods
1	Specific gravity	IS 2720 Part 3, Section 2 (1981)
2	Moisture content (%)	IS 2720 Part 2 (1973).
3	Atterberg limits (%)	IS 2720 Part 5 (1970)
4	Particle size distribution (mm)	IS 2720 Part 4 (1975)
5	Compaction test (Standard Proctor) (g/cm^3 and %)	IS 2720 Part 3, Section 2 (1981)
6	California Bearing Ratio (%)	IS 2720 Part 16 (1987)

4. Plastic Limit Test

20g of soil sample was taken from liquid limit sample. By spreading and mixing the soil repeatedly on a glass plate or in a mixing/storage dish, the water content of the soil was lowered to a consistency that allowed it to be rolled without clinging to hands.

From the plastic limit specimen, 1.5 to 2.0g of soil was selected and made to form an ellipsoidal bulk. With just enough pressure, the mass was rolled between the palm or fingers and a ground glass plate to create a thread that had the same diameter all the way through. The diameter of the thread was further adjusted on each stroke until it reached 3.2 mm, with the rolling rate typically set at 80-90 strokes per minute. Once the thread reached a diameter of 3.2 mm, it was broken into multiple pieces, squished together, then kneaded between each hand's thumb and index finger before being reshaped into an ellipsoidal mass in preparation for rolling again. The rolling, gathering, kneading, and rolling procedure was repeated until the thread could no longer maintain a 3.2 mm diameter and disintegrated under the necessary rolling pressure. The pieces of crumbled thread were collected and put in a container with a known mass; it was then covered immediately. After that, another 1.5–2.0g amount of soil was extracted from the plastic limit specimen, and the process was repeated until at least 6g of soil was in each container.

5. Sieve Analysis

The test was conducted by arranging the sieve set including the pan and lid to form a sieving column, with the aperture diameters decreasing from top to bottom. After being added to the sieve column, the aggregate sample was vigorously shaken with a mechanical shaker. Subsequently, the sieve stack was separated one after the other, and each sieve was manually shaken to ensure no material was lost. The retained materials on each sieve and in the pan were weighed and recorded.

6. Compaction Test

A suitable amount of representative soil was removed, allowed to dry naturally, and then crushed with a rubber mallet. After that, the dirt was put through a No. 4 sieve, and any particles that were left behind were removed. A sample of soil weighing about 3 kg was chosen, and water was added to lower the soil's water content down to roughly 5% less than the estimated ideal moisture content. A 4% initial water content was ideal for coarse-grained soil while a 10% beginning water content was intended for fine-grained soil. Water and soil were well combined. After cleaning, the mold's height, diameter, and weight were determined without the collar. After that, the collar was put on, and a rammer was used to crush the wet soil into three equal layers, giving each layer equal blows. To achieve the full height of the mold with the collar, 25 blows were usually administered for a mold with a 4-inch diameter and 56 blows for a mold with a 6-inch diameter.

Following compaction, the soil was leveled off at the top of the mold and the collar was taken off. Next, the base plate and mold's exteriors were cleaned and weighed. After the soil was carefully taken out of the mold and split, a 100-gram sample was collected to determine the water content. Broken up lumps of soil were combined with the tray's remaining soil. For every trial after that, a small amount of more water was gradually added to raise the water content by two to three percent. After every increase in water, the compaction process was carried out once again until the bulk of the compressed soil stopped falling. For every trial, the dry density and water content were computed.

A compaction curve was drawn, with the ordinate representing dry density and the abscissa representing water content. The maximum dry density was determined to be the matching dry density, and the optimal moisture content was determined to be the water content at the peak of the curve.

7. California Bearing test

The California Bearing Ratio (CBR) test procedure is described in this section.

A. Specimen Preparation

The soil sample was sieved using a ¾ in (19 mm) sieve. Three sample specimens totaling 6.8 kg each were created after sieving. Using around 10, 30, and 56 blows, respectively, specimens 1, 2, and 3 were compacted to produce differences in the percentage of maximum dry density. To preserve the ideal water content, the specimens were combined with an adequate amount of water. The extension collar was used to secure the mold to the base plate, and the weight was recorded. A filter paper was placed on top of a spacer disk, which was inserted into the mold. Three layers of earth were added to the mold. For specimen 1, for instance, the rammer was used ten times per layer to achieve compaction. Both before and after the compaction process, the material's water content was measured. Then, the extension collar was taken off, and the top of the mold was smoothed by trimming it with a straightedge. The same methods mentioned above were used to condense the other two specimens. After removing the base plate and spacer disk, the weight of the mold with the compacted dirt was calculated. After inverting the mold and soil, a coarse filter paper was used to secure the base plate to the mold.

B. Soaking

Over the base plate, a predetermined weight—typically 4.54 kg—was added as a surcharge. The sample was submerged in water for around four days, or ninety-six hours. To calculate the percentage of the specimen's initial height that swelled, the specimen's height was measured both before and after soaking. After soaking in the water for four days, the mold was taken out. Along with removing the base plate, filter paper, and surcharge weights, the mass of the mold plus soil was calculated.

C. Load Test

The mold was placed beneath the compression machine's penetration piston. Surcharge weight of 4.54 kg was applied to the top of the mould. The load was applied at a constant penetration rate, starting at 0.05 in. (1.27 mm)/min. During loading, the piston pierced through the earth. The device featured two indicators: a proving ring that showed the load used to reach that penetration and a dial gauge that showed the penetration. Proving ring readings and their corresponding penetrations were recorded. The piston load was calculated by multiplying the proving ring values by the machine constant. The piston load was used to compute the penetration stress. A strain curve was plotted against stress. If the curve was concave upward near the origin, adjustments were made according to the guidelines.

III. Results and Discussion

1. Natural Moisture Content

The natural moisture content of the subgrade materials was found to have a significant impact on their geotechnical properties. The results showed that the natural moisture content of the materials ranged from 10% to 25%, with an average value of 17%. This suggests that the materials were relatively dry, which is consistent with the local climate conditions. The natural moisture content was found to have a strong correlation with the compaction characteristics of the materials. The materials with higher natural moisture content were found to have lower maximum dry density and optimal moisture content values, indicating that they were more difficult to compact. This is because the natural moisture content affects the soil's ability to hold water, which in turn affects its compaction behavior. The natural moisture content also had an impact on the CBR and UCS values of the materials. The materials with higher natural moisture content were found to have lower CBR and UCS values, indicating that they were weaker and more prone to deformation. This is because the natural moisture content affects the soil's strength and stiffness, which in turn affects its ability to resist loads. The average natural moisture content of the clayey, sandy and the mixture of clayey and sandy soils are 7.9%, 2.2% and 4.6% respectively. Season to season, the natural moisture content of the soil varies, reaching its maximum during the rainy season and its lowest during the dry season. According to [20], the natural moisture content of soil in sand and gravel can range from less than 5% to 50%. The lateritic soil samples have a natural moisture content that varies from 17% to 25%. However, the moisture contents obtained for the soil under study was out of the range stated by [20]. This may be due to the season (rainy) at which the sample were obtained.

2. Sieve Analysis

The results of the sieve analysis of the soil samples are presented using the particle size distribution curve shown in **Fig. 2**. The chart presents the plot of the percentage finer of the soil sample against the diameter of soil particles, on a logarithmic scale. The sieve analysis will be used in addition to other soil parameters to classify the three soils on the AASHTO and Unified Soil Classification Systems. The calculated coefficient of uniformity (Cu) and the coefficient of curvature (Cc) of the S2 soil are 3.16 and 1.01 respectively. Arora [21] stated that the larger the numerical value of Cu, the more the range of particles and that for a well graded soil, the value of coefficient of curvature lies between 1 and 3. Hence, the soil S2 is a well graded soil.

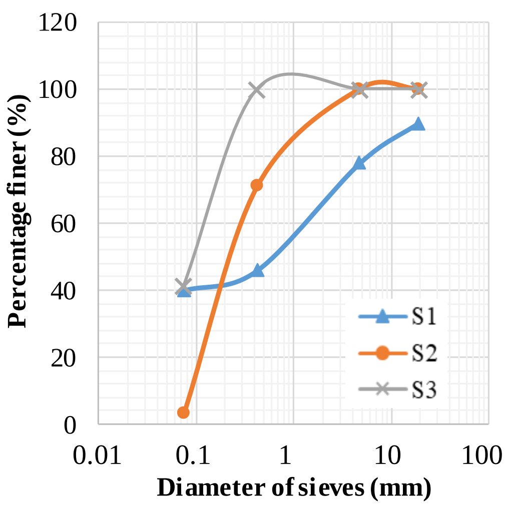

Figure 2. *Particle size distribution curves of the three soils, S1 - clayey, S2 - sandy, and S3 - 50% clay +50% sand*

3. Atterberg Limits

The Atterberg limits of a soil defines its plasticity, the ability of a soil to undergo deformation without cracking or fracturing [21]. The summary of the Atterberg limits, the liquid limit, the plastic limit, the plasticity index and the shrinkage limit of the soils tested is presented in the **Fig. 3**. From the figure, it can be deduced that the liquid limit and the plastic limit of the soil S1 initially increased upon the addition of gum Arabic and maximum liquid limit was observed at the addition of 3% gum Arabic (79%). Further addition of gum Arabic after the 3% addition reduced the liquid limit and plastic limit. However, the addition of gum Arabic first reduced the shrinkage limit of S1 soil and later at 3% addition of gum Arabic, maximum shrinkage limit was recorded (9%).

The addition of gum Arabic to S2 soil gives the soil plasticity, hence, it can be generally said that the liquid limit, plastic limit, plasticity index and the shrinkage limit of S2 soil were increased by the addition of gum Arabic. The maximum liquid limit of S2 soil was observed at the 6% addition of gum Arabic (19%), whereas the maximum plasticity index of the S2 soil (8%) was recorded at the addition of 12% gum Arabic.

The addition of gum Arabic to S3 soil generally lowers the liquid limit, plastic limit and the plasticity index of the soil. The liquid limit of the natural soil S3, S3+1.5 gum Arabic, S3+3% gum Arabic, S3+6% gum Arabic and S3+12% gum Arabic were observed to 44%. 28%, 30%, 24%, and 26% respectively

4. Index Properties of Soil

The summary of the index properties and the classification of the soils treated are presented in Table 3. Soils S1 and S2 appeared with a reddish-brown and light brown colour respectively. The colour of soil S1 indicates that it is most likely from a clayey soil family. Using the particle size distribution and the Atterberg limit results, the soils under study, S1, S2 and S3 have been classified as A-7-6 (7), A-3 (0) and A-5 (1) on the AASHTO classification system, and SC (Clayey sand), SW (Well graded sand) and SP (poorly graded sand) on the Unified Soil Classification Systems respectively. The liquid and plastic limits of the soils S1 and S3 are 50% and 18% and, 44 and 17 respectively. Hence, the soil S1 has the highest plasticity index value of 32% (**Table 3**). Liquid limits of no more than 80% for subgrade and no more than 35% for sub base and base course materials are advised by the Federal Ministry of Works and Housing Specification (1997), while the plasticity index of no more than 5% for subgrade and no more than 12% for both sub base and base course is advised. Although soils S1 and S3 have a certain degree of flexibility, it is evident from their LL, PL, and PI values that these two types of soils are better suited for usage as earth fill and subgrade. According to Arora (2008), a subgrade that scores zero on the group index is considered good, while a subgrade that scores twenty or above is considered very poor. From this statement, the natural soil S1, S2 and S3 are all suitable pavement materials with regards to the value of group index obtained.

5. Compaction

The results of the compaction test are presented in **Fig. 4** and **Fig. 5**. **Fig. 4** shows the variation of maximum dry densities of the three soils S1, S2 and S3 with gum Arabic additions.

Generally, the maximum dry densities of all three samples initially increased upon the addition of gum Arabic after which it then decreased. From the results, maximum dry densities of S1 soil with varying gum Arabic percentages of 0, 1.5, 3, 6 and 12% are 1.62 g/cm^3, 1.75 g/cm^3, 1.73 g/cm^3, 1.61 g/cm^3 and 1.57 g/cm^3 respectively. Hence, the peak maximum dry density of 1.75 was observed (at the addition of 1.5% gum Arabic) with a percentage

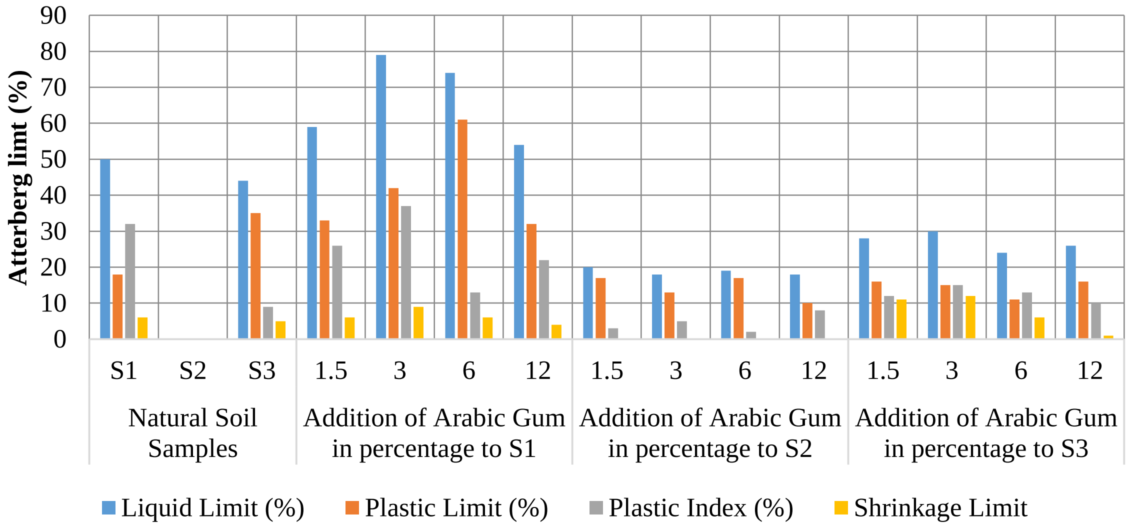

Figure 3. *A bar chart showing the Atterberg limits of the soils, S1 - clayey, S2 - sandy, and S3 - 50% clay +50% sand.*

Table 3. *Summary of Index Properties*

Properties	S1	S2	S3
Colour	Reddish Brown	Light brown	Reddish
Specific Gravity (Gs)	2.78	2.66	2.7
Percentage passing BS No 200 sieve	40	3	41
AASHTO Classification	A-7-6	A-3	A-5
Group Index	7	0	1
USCS Classification	SC	SW	SP
Natural Moisture Content (%)	7.9	2.2	4.6
Liquid Limit (%)	50		44
Plastic Limit (%)	18		17
Plasticity Index (%)	32		27
Shrinkage Limit (%)	6		5

increase of 8.02% with respect to the maximum dry density of the natural soil.

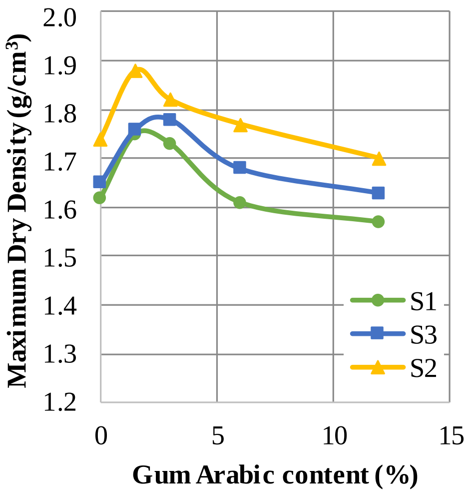

Figure 4. *Variation of the maximum dry densities of the soil samples with gum Arabic content*

Also, the maximum dry densities of S2 soil with varying gum Arabic percentages of 0, 1.5, 3, 6 and 12% are 1.74 g/cm^3, 1.88 g/cm^3, 1.82 g/cm^3, 1.77 g/cm^3 and 1.70 g/cm^3 respectively. Hence, the peak maximum dry density of 1.88 was observed for soil S2 (at the addition of 1.5% gum Arabic) with a percentage increase of 8.05% with respect to the maximum dry density of the natural soil.

Lastly, the maximum dry densities of S2 soil with varying gum Arabic percentages of 0, 1.5, 3, 6 and 12% are 1.65 g/cm^3, 1.76 g/cm^3, 1.78 g/cm^3, 1.68 g/cm^3 and 1.63 g/cm^3 respectively. The peak maximum dry density of 1.78 was observed for soil S2 (at the addition of 3% gum Arabic) with

Fig. 5 depicts the variation of the maximum dry densities of the three soil samples with gum Arabic contents. It can be generally deduced that optimum moisture content and gum Arabic percentage have an inverse relationship over the range of the gum Arabic percentages tested. Hence, the optimum moisture content of the three soils decreased with increase in gum Arabic addition. Meaning that gum Arabic lowers the optimum moisture content of all the three types of soil tested.

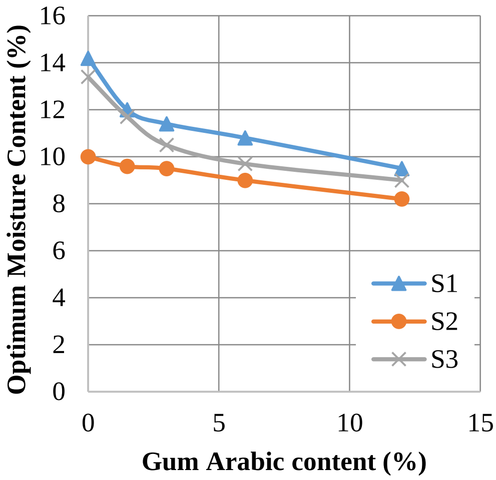

Figure 5. *Variation of the optimum moisture contents of the soil samples with gum Arabic content*

6. California Bearing Ratio (CBR)

The summary of the soaked and unsoaked CBR results of the soils treated with gum Arabic using British standard heavy (BSH) compaction effort is shown in **Fig. 6**. The results show that the CBR values of the soil samples initially improved significantly with the incorporation of gum Arabic and at certain percentages of gum Arabic addition, it decreased. Upon gum Arabic stabilization, the maximum unsoaked CBR values of soils S1, S2, and S3 obtained at 3% addition of gum Arabic were 32.1%, 81.7%, and 48.7% respectively. The maximum soaked CBR values of soils S1, S2, and S3 obtained at 1.5%, 6% and 1.5% additions of gum Arabic were 8.4%, 28.7%, and 16.9% respectively.

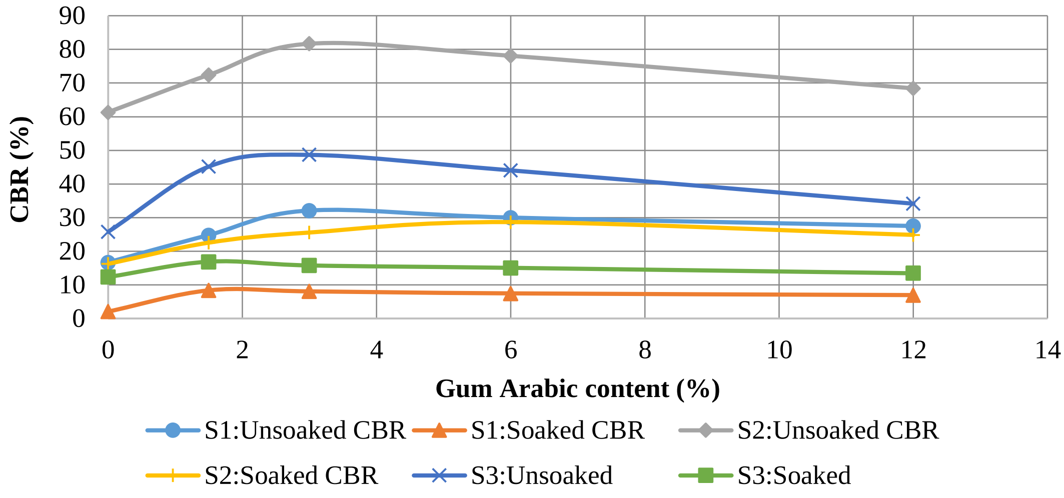

Figure 6. *California Bearing Ratio results*

Bello et al, (2015) stated that the increase in the CBR value could be due to the presence of calcium compound which is required for the formation of CSH. Clause 6201 of the Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement, (1997) states that after at least 48 hours of soaking, the minimum strength for subgrade or fill cannot be less than 10%. With regards to this, the soil samples S2 and S3 treated with the gum Arabic percentages as shown in Fig. 6 did meet the CBR values specified by the Federal Ministry of Works and Housing. The maximum unsoaked CBR values of the three samples S1, S2, and S3 are all higher than 30 %; thus confirming that the stabilized soils may be useful as a subgrade or earth fill material, according to the unsoaked CBR requirements of the Federal Ministry of Works and Housing Specification, (1997).

IV. Conclusion

In conclusion, the application of gum arabic on the geotechnical properties of subgrade materials has shown promising results. The study demonstrated that the addition of gum arabic significantly improves the compaction characteristics, California Bearing Ratio (CBR), and unconfined compressive strength (UCS) of subgrade materials. The natural moisture content of the materials was found to have a significant impact on their geotechnical properties, and the addition of gum arabic helped to mitigate the effects of high moisture content. The results of this study suggest that gum arabic can be used as an effective soil stabilizer to improve the engineering behavior of subgrade materials. The use of gum arabic can lead to improved road performance, reduced maintenance costs, and increased safety. Additionally, the use of gum arabic is environmentally friendly and can be sourced locally, making it a sustainable option for soil stabilization. Further research is recommended to explore the potential of gum arabic in improving the geotechnical properties of subgrade materials. Future studies can investigate the optimal dosage of gum arabic, the effect of gum arabic on other geotechnical properties, and the long-term performance of gum arabic-stabilized subgrade materials.

The following conclusion have been drawn from the results obtained

i. The average natural moisture contents of soils S1, S2 and S3 were determined to be 7.9%, 2.2% and 4.6% respectively. The liquid limit, plastic limit and shrinkage limit of S1 soil were determined as 50%, 18% and 60% respectively while the liquid limit, plastic limit and shrinkage limit of S3 soil were determined as 44%, 17% and 5% respectively.

ii. The soils S1, S2 and S3 have been classified as A-7-6 (7), A-3 (0) and A-5(1) on the AASHTO classification system, and SC (Clayey sand), SW (Well graded sand) and SP (poorly graded sand) on the Unified Soil Classification Systems respectively.

iii. Using British standard heavy compaction, maximum dry densities of S1 soil with varying gum Arabic percentages of 0, 1.5, 3, 6 and 12% are 1.62 g/cm^3, 1.75 g/cm^3, 1.73 g/cm^3, 1.61 g/cm^3 and 1.57 g/cm^3 respectively. Hence, the peak maximum dry density of 1.75 was observed (at the addition of 1.5% gum Arabic) with a percentage increase of 8.02% with respect to the maximum dry density of the natural soil. Also, the maximum dry densities of S2 soil with varying gum Arabic percentages of 0, 1.5, 3, 6 and 12% are 1.74 g/cm^3, 1.88 g/cm^3, 1.82 g/cm^3, 1.77 g/cm^3 and 1.70 g/cm^3 respectively. Hence, the peak maximum dry density of 1.88 was observed for soil S2 (at the addition of 1.5% gum

Arabic) with a percentage increase of 8.05% with respect to the maximum dry density of the natural soil. The maximum dry densities of S2 soil with varying gum Arabic percentages of 0, 1.5%, 3%, 6% and 12% are 1.65 g/cm^3, 1.76 g/cm^3, 1.78 g/cm^3, 1.68 g/cm^3 and 1.63 g/cm^3 respectively. The peak maximum dry density of 1.78 was observed for soil S2 (at the addition of 3% gum Arabic) with a percentage increase of 7.88%% with respect to the maximum dry density of the natural soil.

iv. The maximum unsoaked CBR values of soils S1, S2 and S3 obtained at 3% addition of gum Arabic were 32.1%, 81.7% and 48.7% respectively. Whereas, maximum soaked CBR values of soils S1, S2 and S3 obtained at 1.5%, 6% and 1.5% additions of gum Arabic were 8.4%, 28.7% and 16.9% respectively.

V. Recommendations

The following recommendations are given in light of the research's findings.

i. The study recommends the use of 3% addition of gum Arabic in improving the California bearing ratio of A-7-6 (AASHTO classification) or SC (USCS)

ii. The use of 1.5% addition of gum Arabic to raise the dry density of A-7-6, and A-5 soils

iii. Since this work checked 1.5n% additions of gum Arabic to soils, for n = 1, 2, 4, 8, the study recommends further research works in testing for the influence of lower ratios of gum Arabic additions on soils.

iv. Area of interest for further research should include investigation into the possibilities of using Gum Arabic to 'glue' the ballast layer

VI. Limitations

When compared to conventional stabilizers like cement, Gum Arabic may be more expensive, particularly if it is not readily available in the region. This could limit its widespread use in large-scale projects. Additionally, while the environmental benefits of using a natural product like Gum Arabic are appealing, the overall cost-effectiveness needs to be evaluated against common alternatives such as cement or lime.

The application process of Gum Arabic may require specialized knowledge or equipment for consistent and even distribution within the soil matrix. In contrast, methods like cement stabilization are well-known and have an established process that is relatively easy to implement across various project scales. Furthermore, the curing period of Gum Arabic-stabilized soils and their long-term performance under different environmental conditions still require more extensive study.

Author Contributions

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Disclosure Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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