Effect of gum Arabic content on maximum dry density and optimum moisture content of laterite soil

Alladjo Rimbarngaye a,*, John N. Mwerob, Erick K. Ronohc

a Department of Civil and Construction Engineering, Pan African University Institute for Basic Sciences, Technology and Innovation Hosted at Jomo Kenyatta University of Agriculture and Technology, Kenya
b Department of Civil and Construction Engineering, University of Nairobi, Kenya
c Department of Agricultural and Biosystems Engineering, Jomo Kenyatta University of Agriculture and Technology, Kenya

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ABSTRACT

Soil is a material that has been used in construction for centuries and nowadays represents one third of the world’s construction. Cement and lime which are common stabilisers used to make soil-based blocks durable have been found to be harmful to the environment. Therefore, finding environmentally friendly materials as a substitute for cement and lime is of vital importance. In Africa, gum Arabic is a widely available organic material (a biopolymer). The objective of this study was therefore to evaluate the effects of gum Arabic on maximum dry density and optimum moisture content of laterite soil in order to use gum Arabic as a binder for the stabilization of laterite soil blocks. Light compaction test (Standard Proctor Test) was carried out for the mixture of laterite soil, sand, and gum Arabic. The proportion of sand was 20% by mass of laterite soil in this mixture; the gum Arabic was varied from 0 to 10% with a step of 2, by mass of laterite soil. The results showed that the maximum dry density decreased from 1883 kg/m³ to 1693 kg/m³ after the addition of 0%–10% gum Arabic in laterite soil, respectively. Whereas the optimum moisture content increased from 14.88% to 18.38% after the addition of 0%–10% gum Arabic, respectively. The observed results of the maximum dry density have been found to be within the recommended range. Based on the findings from this study, gum Arabic can be recommended as binder in the stabilisation of laterite blocks.

1. Introduction

Since the dawn of time, people have used soil as a basic building material. Even in the 21st century, more than one third of humanity resides in earthen houses [1]. Earth-based constructions are more climate-friendly, eco-friendly, accessible, and inexpensive for everyone, and provide a vital cultural relationship with nature [1]. Nevertheless, these earth-based constructions encounter problems of durability and brittleness, low mechanical strength, or high variability in the reported properties. Various traditional admixtures like lime, fly ash and cement have often been applied to stabilize soils to overcome these difficulties and create sustainable buildings [2]. Cement is the most extensively utilized of the materials described above. On the other hand, the use of cement poses a lot of problems for the environment because of CO₂ emissions [2]. As a solution for soil stabilisation, natural biopolymers have been suggested to mitigate the negative effects of cement on the environment and to use eco-friendly materials [3, 4, 5]. Furthermore, some studies have been conducted on specific gums for use in stabilising soils, namely xanthan gum, gellan gum, agar gum, polyacrylamide, and guar gum [2].

Gum Arabic (GA) is a complex substance with both hydrophilic and hydrophobic properties [6]. Hydrophilic and hydrophobic interactions balance the physicochemical reactions of GA. The operational characteristics of GA are strongly correlated with its composition, which conditions its solubility, viscosity, interaction degree with water and oil in an emulsion, and its microencapsulation capacity [6]. Because of their high viscosity, many gums cannot dissolve at concentrations above 5% with water. Instead, GA can dissolve in water at a 50% w/v (water/volume) concentration, forming an acidic fluid solution (pH = 4.5) [7].

Recent work has demonstrated the applicability of GA in concrete [8, 9, 10, 11, 12]. GA has been demonstrated to possess high-water solubility and hydrophobic properties [6]. Hydrophilic and hydrophobic interactions balance the physicochemical reactions of GA. The operational characteristics of GA are strongly correlated with its composition, which conditions its solubility, viscosity, interaction degree with water and oil in an emulsion, and its microencapsulation capacity [6]. Because of their high viscosity, many gums cannot dissolve at concentrations above 5% with water. Instead, GA can dissolve in water at a 50% w/v (water/volume) concentration, forming an acidic fluid solution (pH = 4.5) [7].

Recent work has demonstrated the applicability of GA in concrete [8, 9, 10, 11, 12]. GA has been demonstrated to possess high-water solubility and low viscosity [13]. In addition, GA has been used as an additive in a ceramic glaze binder to decrease the chance of damage throughout manufacturing [14]. Adding GA to concrete has also been proven in...
studies to increase the characteristics of concrete owing to the inclusion of minerals such as sepiolite, palygorskite, and mordenite [8]. Concrete containing GA improved in compressive strength with the amount of GA used, and the dosage range of 0.50–0.75 percent is appropriate [8]. The increase in compressive strength is related to the fact that calcium silicate hydrate (C–S–H) is produced from the reaction between cement and GA, which is more densified and abundant than cement, thus improving concrete properties and providing better performance [11, 12]. In the case of lime-based soil stabilisation, however, the formation of C–S–H has been found to be important for stabilising soils [15].

GA, on the other hand, has been demonstrated to be a double role concrete additive: a set accelerator (SA) and a normal water reduction (WR) when used at 0.8% by weight of cement, according to Table 12 of [16]. It achieves an 11.5% water reduction while maintaining a standard concrete mix consistency [17]. Additionally, using GA in concrete has been shown to be suitable as a superplasticizer in self-compacting concrete at a dosage of 8% by cement weight for 1.0, 0.9 and 0.8 water-to-powder ratios [9]. The use of GA as a retarding admixture in mortar has been demonstrated at temperatures ranging from 23 °C to 25 °C when used as a water-reducing admixture in mortar of cement [10].

Research has been conducted on natural ingredients for earth-based construction. It is based on an ancestor’s oral tradition passed down through generations [1]. One example of such a natural ingredient is GA. Some laboratory tests were conducted to demonstrate the significance of the usage of natural materials in earth building. From those studies, limited to erosion and abrasion tests, it was suggested that further investigation of its natural constituents should be carried out to demonstrate the effectiveness of its use in earth-based buildings [1]. Furthermore, it has been demonstrated that GA is commonly utilized as a stabilizer and waterproofing ingredient in mud plasters in Africa [18]. GA, on the other hand, has demonstrated its applicability as a binder in micro-concrete tile production [19] and sawdust and wood chip board production [20]. Although there is evidence from previous work that GA can be used in concrete and mud plasters, information on its use in stabilised earth blocks is lacking. This research was undertaken to determine the effect of GA content on the maximum dry density and optimum moisture content of laterite soil to show the possible use of GA for further studies on the stabilisation of earth blocks.

2. Materials and methods

2.1. Materials

The research was carried out at the Jomo Kenyatta University of Agriculture and Technology’s (JIKUAT) Civil Engineering Laboratory in Kenya. GA, laterite soil, river sand, and water were used in this study. The GA used in this study was sourced locally in Kenya. It came from the county of Isiolo in central Kenya. The laterite soil was obtained locally in Juja, within the boundaries of JKUAT. Meru, a town in eastern Kenya, was used to collect river sand. The water used for mixing and curing was tapable according to the standard’s specifications [21].

2.2. Methods

2.2.1. Crushing of gum Arabic

After procuring the GA, it was crushed into powder. As it was dry, there was no need to dry it further. Then, after crushing, it was sieved through a sieve of 0.6 mm. The retained GA on that sieve was crushed and sieved until the whole GA was reduced to powder. Figure 1a shows the GA in raw state and Figure 1b shows the machine used to crush the GA. Figure 1c shows the powder of the GA obtained after sieving.

2.2.2. Determining the physical properties of the laterite soil

The moisture content, the Atterberg limits, the specific gravity and the compaction test of the laterite soil were carried out in accordance with [22].

2.2.3. Determining the physical properties of the sand

The particle size distribution, the specific gravity, the water absorption, the moisture content and the silt content of the sand were determined in accordance with [23, 24, 25, 26], respectively.

2.2.4. Compaction test with different percentages of gum Arabic

In this research, the light compaction test (standard proctor) was used in accordance with [22]. A quantity of moist soil mixing with 20% of sand and different percentages of GA in powder form (0, 2, 4, 6, 8 and 10%) was used. For each mix, an increment of 50 ml of water was used for each compaction.

3. Results and discussion

3.1. Properties of laterite soil

3.1.1. Physical properties of laterite soil

The basic properties of the laterite soil are shown in Table 1 and Figure 2. Figure 2 gives the particle size distribution of the laterite soil while Table 1 shows the physical properties of laterite soil. The dry density of laterite soil is 1883 kg/m³. Based on research, it has been observed that the density of compressed stabilized soil bricks is in the range of 1500–2000 kg/m³ [27]. Thus, the density of laterite soil falls within this range. On the other hand, the percentage of sand in this soil is still not in the range of 60–70% as recommended by [28]. The soil has only 20% sand. For this reason, a certain percentage of sand required to be added to improve the quality of the soil during block production.

In addition, the plasticity index of the soil is 18%. Burroughs [29] found that a good soil for stabilisation should have a plasticity index below 25%. This means that the plasticity index of the murram soil studied does not exceed this limit. Soil with a plasticity index greater than 20% is not suitable for manual compaction [30]. Such soil develops much more shrinkage and the compressive strength is low. Based on these analyses, it can be concluded that the lateritic soil studied is of good quality and can be used for block production.

Table 1. Physical properties of laterite soil.

| Property                        | Value |
|---------------------------------|-------|
| Proctor test:                   |       |
| Optimum moisture content (%)    | 15    |
| Maximum dry density (kg/m³)     | 1883  |
| Atterberg limits:               |       |
| Liquid limit (%)                | 38    |
| Plastic limit (%)               | 20    |
| Plasticity index (%)            | 18    |
| Linear shrinkage (%)            | 14    |
| Soil classification (BS 1377, 1990) | Clayey sandy GRAVEL |
| Particle size distribution:     |       |
| Gravel (60-2 mm) (%)            | 55    |
| Sand (2-0.06 mm) (%)            | 20    |
| Silt (0.06–0.002 mm) (%)        | 7     |
| Clay (<0.002 mm) (%)            | 18    |
According to [22], pebbles are classified as having grain size of 200 to 60 mm, gravels have grain size of 60 to 2 mm, sands have 2 to 0.06 mm grain size, 0.06 to 0.002 mm for silts and 0.002 to 0 mm for clays. From this classification, the different percentages of gravel, sand, silt and clay were determined for each soil type, as shown in Figure 2.

The liquid limit of the laterite soil studied is 38%. Burroughs [29], in his research, recommended that a good soil for earth block stabilisation should have a liquid limit of less than 40%. A soil with a LL above 40% results in low compressive strength [29]. Since the LL of the studied laterite soil is below 40%, it can be used for block production.

In addition, the plastic limit of the studied soil is 20%. The higher the plasticity limit, the more clayey the soil is. According to [29], a soil with a plastic limit between 16-19% is favourable for the stabilisation of earth blocks. However, the value obtained is not in this range and it is slightly above the upper value of the range. This explains the high shrinkage limit observed (14%).

The shrinkage limit of the studied soil is 14%. This value is higher than the recommended value (11%) for the compaction of earth constructions [31]. It is therefore necessary to add sand to the lateritic soil in order to reduce this shrinkage and to decrease the binder content. The greater the shrinkage, the greater the amount of binder required to stabilise the soil.

Finally, the particle size analysis shows that gravel is the dominant element with 55%. Sand and clay represent respectively 20% and 18% in this soil. Silt represents 7%. From these percentages, BS [22] classifies this soil as a clayey sandy GRAVEL soil.

### 3.1.2. Specific gravity of laterite soil

The specific gravity of the lateritic soil used in this research was determined according to [22]. The specific gravity value obtained was 2.64. According to [32], laterites are generally reddish-brown soils with a specific gravity of 2.5–3.6, and generally consist of secondary minerals of aluminium, quartz and kaolinite. It should therefore be noted that the specific gravity value obtained is within this range. Based on these analyses, it can be concluded that the soil studied is a laterite soil and can be used for block production.

### 3.2. Properties of fine aggregate

Table 2 presents the physical properties of sand, including silt content, water absorption, fineness modulus, specific gravity and moisture content. As shown in the table, the results of the sand are satisfactory according to the specified standards.

| Designation         | Value    | Limit    | Remarks | Code |
|---------------------|----------|----------|---------|------|
| Silt content        | 5.63 %   | <6%      | Good    | [33] |
| Water absorption    | 1.97%    | <3%      | Good    | [33] |
| Fineness modulus    | 2.81     | 2.1–4.0 | Good    | [34] |
| Specific gravity    | 2.69     | 2.60–2.80| Good    | [35] |
| Moisture content    | 0.88%    | <2.5%    | Good    | [36] |

The specific gravity of sand is 2.69 and is within the limit values set by [35]. In practice, the specific gravity makes it possible to tell how much lighter or heavier a material is than water. According to [37], any material with a specific gravity of less than 2.40 is considered lightweight material. Thus, based on the specific gravity of sand found, it can be considered as a heavy weight and can contribute to increase in the density of the blocks. In addition, the results of moisture content of the sand showed that the value of moisture content of the sand used was 0.88%. This value is therefore lower than the limit set by the [36] standard. This means that this value is negligible and cannot influence the optimum moisture content required for the compaction test and block production to achieve the maximum dry density.

The modulus of fineness of the sand was 2.81. According to [34], the modulus of fineness should be in the range 2.1–4.0. Thus, the modulus of fineness of the sand obtained is in this range.

Moreover, the classification is within the lower and upper limits as per the standard [41], as shown in Figure 3.
this means that in the case of compressed stabilised earth blocks, the same scenario can be observed. That is, if the sand particles are fine, it would require more cement to ensure good particle bonding. Conversely, if the particles are coarse, the quantity of cement will decrease and this would make the work difficult because of the low workability [38, 39]. Since the result of particle size distribution is within the lower and upper limits, it can be concluded the sand studied could be used for this research.

3.3. Compaction test on laterite soils

Houben et al. [43] recommended a soil containing 0–40% gravel, 25–80% sand, 10–25% silt and 8–30% clay for the production of blocks. Based on the result of the sieve size analysis obtained, the laterite soil selected contains 20% sand and 18% clay. However, the shrinkage limit of the studied soil is 14%. This value is higher than the value recommended (11%) for the purpose of compaction for earth construction [31]. Therefore, it was necessary to add sand to the laterite soil in order to reduce this shrinkage and reduce the binder content. The greater the shrinkage, the greater the amount of binder required for soil stabilization. According to [44], a large proportion of clay in the soil causes unacceptable swelling, while a small proportion does not contribute to good adhesion between soil particles. Oyelami et. al [45] confirmed this statement by indicating that the very high clay content may cause shrinkage and cracking of the blocks. Therefore, a certain percentage of sand must be added to modify the grading of the selected soil. To do this, 20% sand was added to the soil and compaction tests were carried out by varying GA from 0 to 10% by mass weight of the laterite soil in order to determine the maximum dry density for an optimal moisture content to produce blocks.

3.3.1. Effect of varying the gum Arabic content on maximum dry density and optimum moisture content of the laterite soil

Figure 4 shows the results of laterite soil compaction tests (dry density versus moisture content) for the different percentages of GA used. It is noted that, in general, the addition of GA to laterite soil decreases its maximum dry density (MDD). This decrease in MDD ranging from 1883 kg/m³ to 1693 kg/m³ was as a result of varying GA from 0 to 10% by mass of laterite soil, respectively. On the other hand, it is noticed that the optimum moisture content (OMC) increases with the GA content in the soil. Therefore, the higher the GA content per mass of soil, the higher the OMC increases, thus reducing the MDD.

Figure 5 shows the results of MDD for different GA contents. The figure clearly shows that the MDD decreases with increasing GA content. That is, the GA causes a reduction of the density because of its lightweight (its specific gravity was 1.47) [37], [46]. Therefore, this can reduce the dry density of the blocks. However, it is important to note that all the density values obtained fall within the range of 1500–2000 kg/m³, which corresponds to the interval in which the density of the stabilised earth blocks is found [27]. In addition, the fact that GA will contribute to the reduction of dry density of blocks while allowing a higher compressive strength [46] has rather a great advantage in the construction industry. Indeed, this contributes to reduce the thermal conductivity of these blocks, resulting in thermal comfort inside the houses [47]. It has been found by the previous researches that the thermal conductivity of the blocks decreases with the decrease of the density of the blocks [47]. As shown in Figure 5, a trendline has also been established and a polynomial correlation is observed between maximum dry density and GA content. The polynomial correlation coefficient is of the magnitude of 0.9972. This is a strong negative correlation coefficient. From a statistical point of view, it results in a strong correlation between the maximum dry density and the GA content.

Figure 6 is the plot of OMC versus different GA contents. It is important to notice that the maximum achieved density for each mix is dependent on the quantity of GA; the higher the GA content, the higher the moisture content at the maximum density achieved. This is due to the viscosity of the GA [48]. This means that the density of blocks will decrease. A polynomial trend line was also established to show a correlation between the optimum moisture content and the GA content. The polynomial correlation coefficient is of the order of 0.9183. This is a strong positive correlation coefficient. From a statistical point of view, it shows a strong correlation between the optimal moisture content and the GA content.

Ayeleed et al. [49], in their research work on two different gums (guar gum and xanthan gum), observed the same effects of these gums on soil compaction by varying the concentration of these gums from 0 to 2%. For the xanthan gum samples, by varying the concentration from 0 to 2%, the maximum dry density was reduced from 19 kN/m³ (1937.46 kg/m³) to 17.2 kN/m³ (1753.91 kg/m³). The maximum dry density reached 16.7 kN/m³ (1702.93 kg/m³) in the case of guar gum for a biopolymer concentration of 2%. On the other hand, they also observed an increase in the optimum moisture content. This increase in OMC ranged from 12.4% (at 0% concentration) to 15.3% and 14.4% (at 2% concentration) for guar gum and xanthan gum, respectively. Similarly, in the studies of [48], by varying the concentration of xanthan gum from 0 to 2.5% in soil compaction, the MDD decreased from 16 kN/m³ (1631.55 kg/m³) to
13.7 kN/m³ (1397.01 kg/m³). On the other hand, the OMC increased from 32% to 37.3%.

The decrease in the MDD observed may be due to the physical characteristic of the GA biopolymer, in particular its viscosity and the weight of the particles. Due to the low viscosity of GA, since the particles have a light weight, they move away from each other [48, 49]. This leads to a reduction in the maximum dry density of the laterite soil [48, 49]. In addition, the higher the content of GA, the higher the viscosity [49]. This means that the OMC increases as the GA content increases [48].

4. Conclusions

The following conclusions have been deduced from the results of the above-mentioned experimental work.

1. The MDD decreased with the increase in GA content.
2. The OMC increased with the increase in GA content.
3. Despite the decrease in the maximum dry density with the increase in GA, the density values obtained still fell within the range of 1500–2000 kg/m³, which corresponds to the density of the stabilised earth blocks.
4. By varying the GA content from 0 to 10%, it implies that GA could be used in the stabilization of laterite soil blocks without taking the dry density of the laterite soil out of the range of density values observed in previous research.
5. The fact that GA will contribute to the reduction of dry density of blocks has a great advantage as this contributes to the reduction of the thermal conductivity of the blocks, resulting in thermal comfort inside the houses. It has been found by the previous researches that the thermal conductivity of the blocks decreases with the decrease of the density of the blocks.

Declarations

Author contribution statement

Alladjo Rimbarngaye: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.
John N. Mwero, Erick K. Ronoh: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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