



Influence of limestone and bagasse ash on the physical and mechanical characteristics of a clay soil stabilized with sugar cane molasses

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Available online at: www.isca.in, www.isca.me

Received 27th November 2024, revised 4th August 2025, accepted 18th September 2025

Abstract

This treaty was carried out as part of the clay stabilization for better use in road works. Limestone (4%; 6% and 8%) and bagasse ash (4%; 6% and 8%) were added to the clay soil stabilized at 8% sugarcane molasses on the one hand, then a combination of the two admixtures (4%Ca +4%Ba; 6%Ca+6%Ba and 8%Ca+8%Ba) was used. The analysis of the influence of these admixtures on the physico-mechanical behaviour of this soil has shown that: the mechanical compressive and tensile strengths are interesting for all formulations for limestone. The percentage of 8% limestone gives more gain in compressive strength (4.65 MPa) and tensile strength (1.2 MPa). The addition of bagasse ash does not provide any gains in compressive and tensile strength in this soil. The optimal percentage of bagasse ash is 4%. The combination of bagasse ash (8%) and limestone (8%) slightly increases the compressive (2 MPa) and tensile strength (0.9 MPa) of this soil: compression (1.85 MPa), tensile strength (0.8 MPa). However, there is a decrease in compressive and tensile strength compared to molasses and limestone-stabilized samples. The addition of 6% limestone reduces water absorption (2.96%) in this soil (5.27%). The addition of 6% of sugarcane bagasse ash contributes to the decrease in water absorption (3.58%) of this soil (5.27%). The combination of bagasse ash (6%) and limestone (6%) does not reduce water absorption. The addition of limestone (6%) reduces the porosity (4.47%) of this soil (6.75%). The addition of bagasse ash (6%) reduces the porosity (4.56%) of this soil (6.75%). The combination of bagasse ash (6%) and limestone (6%) reduces the porosity (4.96%) of this soil (6.75%). We can say that limestone improves the physico-mechanical properties of the soil stabilized by sugar cane molasses. Sugarcane bagasse ash must be added through limestone to stabilize clay soil using molasses.

Keywords: Limestone, bagasse ash, physico-mechanical characteristics, clay soil, sugar cane molasses.

Introduction

Water has a direct effect on soil behaviour, in general on the type of fine-grained soil. It is also an important factor in most geotechnical problems¹.

In the Republic of Congo, the Société Agricole de Raffinage Industriel de Sucre (SARIS), based in the town of Nkayi, dumps sugarcane molasses on dirt roads during the dry season to reach the effects of dust. This somewhat random activity has proven that sugarcane molasses contributes to the stabilization of soil grains. A number of studies have been conducted on soil stabilization using sugarcane molasses. A 12% molasses assay in Nkayi soil resulted in a compressive strength of 4.65MPa². The addition of 8% molasses for the stabilization of Nkayi soils reduced the water absorption coefficient from 25% to 16%, the reduction of micropores and mesopores with a diameter of less than 12nm; but it also seems to have no effect on mesopores with a diameter greater than or equal to 12 nm³.

Nabeel et al. investigated the influence of sugarcane molasses on the stabilization of clay soil. They showed that increasing molasses content from 0% to 8% reduced soil expansion and improved soil stability⁴. Shantanu Bhide et al. investigated the effect of molasses on the compressive strength and workability of concrete mixed with fly ash. They showed that the use of molasses as a plasticizer in concrete complies with the IS 9103:1999 standard for water reduction criteria, molasses can be effectively used as a retarding and water-reducing admixture in concrete. In addition, a maximum increase of 43.9% in compressive strength was observed following the work of Bhide et al⁵. Similarly, Bizualem Taye studied the stabilization of expandable clay soils with molasses and cement. He showed that the combination of cement and molasses is effective in stopping linear shrinkage and eliminating shrinkage cracks that have been observed in soils treated with cement. The addition of molasses to the cement had reduced the fragility of the soil, in addition the soils treated with a combination of cement and molasses had shown higher strength values⁶.

Yibas Mamuye et al. examined the combined effects of molasses and lime treatment on low-quality natural gravel materials used for the construction of the foundation and base course. They showed that molasses alone cannot be used effectively to improve natural gravel used for the construction of the subgrade and base layer. They showed that molasses alone cannot be used effectively to enhance natural gravel for use in base layer construction⁷. Anand Babu Kotta et al. investigated the effect of molasses as a binder on the physical and mechanical properties of iron ore pellets. They showed that molasses promotes the development of viscous forces between the particles and the moisture content of the molasses enhanced the cohesive forces between the particles. This promotes the agglomeration and binding of hyperfine particles⁸.

Manyuchi et al. upgraded charcoal fines and sawdust into briquettes using molasses as a binder. They showed that the combination of sawdust and molasses binder enhanced the agglomeration effect of the coal fines, resulting in a strong, less brittle briquette with an 80% increase in compressive strength⁹. However, in contact with water, this soil stabilized by molasses loses its stability. Indeed, the molasses is leached and then dissolved in contact with water. The need to improve the sustainability of soils stabilized with sugar cane molasses by adding limestone or bagasse ash is becoming an imperative. The aim of our work is to improve the durability of soils stabilized with molasses by adding limestone and bagasse ash. Several formulations were developed and submitted for analysis.

Methodology

Study area: The study area is the town of Nkayi, in the department of Bouenza, in the south-west of Congo Brazzaville. Its location is: 4°9'56" S longitude and 13°17'34" E latitude. During our work, the different materials used are: i. Clay soil: the sampling is carried out in the town of Nkayi, more precisely along the access road of the SARIS CONGO company. The sample is taken at a depth of -50 cm from the level of the natural terrain. It is subjected to various identification and compaction tests. ii. Sugarcane molasses comes from SARIS Congo in Nkayi. In the literature, there are indications of its chemical composition. iii. The limestone used is supplied by SARIS CONGO in the commune of MADINGOU, capital of the department of BOUENZA. iv. Bagasse, made up of crushed plant fibres, represents up to 30% of the material from sugar cane. It also contains an average of 45% water, 48.5% fibre and 2.5% dissolved matter (mainly sugar)².

Climate: The department of Bouenza enjoys a humid tropical climate characterized by: i. two rainy seasons, of roughly equal importance, from October to December with a maximum in November and from March to May, with a maximum in April, but are separated by two dry seasons. ii. the short dry season (January-February) is more likely to slow down the rains; it is all the more marked as the total rainfall is lower. It can sometimes start in December, but its duration remains

approximately constant, around six weeks. On the other hand, the long dry season, which runs from June to September, corresponds to a total cessation of rainfall³.

Molasses used: Nice Nguallat has produced the infrared spectrum of sugar cane molasses from SARIS Congo. In this research work, the results obtained that the region between 1200 and 1000 cm^{-1} is dominated by glycosidic bonds (C-O-C) in combination with other modes such as: (C-O-H), (C-C), (C-H) and is characteristic of polysaccharides³. The region between 1000 and 1200 cm^{-1} is characteristic of sucrose. The region between 950 and 1200 cm^{-1} is characteristic of glucoses. The region between 950 and 400 cm^{-1} is characteristic of fructoses. The peak at 1582 cm^{-1} is characteristic of the C=C bond vibration of an aromatic compound responsible for the coloring of sugarcane molasses such as maltol and furaneol³. These results are useful for our work.

Bagasse ash used: Bagasse ash contains calcium and magnesium oxides in particular.

Limestone used: The limestone used comes from the SARIS limestone production center in the locality of Madingou. According to the manufacturer's information, this limestone contains 50% of calcium carbonate (CaCO_3), so it is calcite.

Soil identification tests: The tests carried out to determine the geotechnical characteristics of the earth material in order to better situate its behaviour are: i. Particle size analysis by sieving with filtering; ii. Atterberg limits; iii. Methylene Blue Tests; iv. Compaction tests (Proctor test).

Making of mud bricks: The bricks are made by compaction with the mould used to make the briquettes. The dimensions of the briquettes are $16 \times 4 \times 4 \text{ cm}^3$, made in groups of three in the moulds. Sugarcane molasses makes up 8% of the sample while limestone and ash from sugarcane bagasse range from 4%, 6%, and 8%.

Procedure: The soil sample is put in the oven at 105°C, then weighed, cooled and sieved with a 250 μm sieve. The manufacture of the briquettes required a quantity of water in relation to the maximum Proctor optimum of the Proctor test, i.e. 22.5% of the sample. Sugarcane molasses with a density of about 1390 kg/m^3 is very soluble in water.

For our study, the mass percentage of each binder is given in relation to the total mass of the sample. After the homogeneity of the mixture, we proceeded to a manual kneading for 7 minutes. i. Sugarcane molasses mix: the amount of molasses is 8% in each sample. ii. Limestone mixture: limestone is added according to the percentages 4%, 6% and 8% of the sample. Sieving is carried out with an 80 μm sieve. iii. Sugarcane bagasse ash mixture: the bagasse has been calcined at room temperature. After calcination, the bagasse ash is sieved with an 80 μm sieve.

Note: We have manufactured a series of briquettes made up of the soil, molasses and limestone assembly as shown in Table-1, a series of briquettes made up of the mixture of soil, limestone, molasses and bagasse ash as shown in Table-2 and a series of briquettes made up of the soil, molasses and bagasse ash assembly as shown in Table-3.

Table-1: Formulation of stabilized specimens for soil, molasses and limestone mixture.

Samples	8% M	8% M + 4% Ca	8% M + 6% Ca	8% M + 8% Ca
Clay	1196 g	1144 g	1118 g	1092 g
Molasses	104 g	104 g	104 g	104 g
Limestone	0	52 g	78 g	104 g
Water	292.5 g	292.5 g	292.5 g	292.5 g
Number of test pieces	3	3	3	3
Total mass of materials	1300 g	1300 g	1300 g	1300 g

Table-2: Stabilized specimen formulation for soil, molasses, limestone and bagasse ash.

Samples	8%M	8%M + 4%Ca + 4%Ba	8%M + 6%Ca + 6%Ba	8%M + 8%Ca + 8%Ba
Clay	1196g	1092g	1040g	988g
Molasses	104g	104g	104g	104g
Limestone	0	52g	78g	104g
Bagasse ash	0	52g	78g	104g
Water	292.5g	292.5g	292.5g	292.5g
Number of test pieces	3	3	3	3
Total mass of materials	1300g	1300g	1300g	1300g

Table-3: Formulation of stabilized specimens for soil, molasses and bagasse ash.

Samples	8%M	8%M + 4%Ba	8%M + 6%Ba	8%M + 8%Ba
Clay	1196g	1144g	1118g	1092g
Molasses	104g	104g	104g	104g
Bagasse ash	0	52g	78g	104g
Water	292.5g	292.5g	292.5g	292.5g
Number of test pieces	3	3	3	3
Total mass of materials	1300g	1300g	1300g	1300g

Note: i. 8%M means: test tubes made by the soil with 8% molasses or the reference sample or the control sample; ii. 8%M+4%Ca means: test tubes made by the ground with 8% molasses and 4% limestone; iii. 8%M+6%Ca means: test tubes made by the ground with 8% molasses and 6% limestone; iv. 8%M+8%Ca means: specimens made by the ground with 8% molasses and 8% limestone; v. 8%M+4%Ca+4%Ba means: specimens made by the ground with 8% molasses, 4% limestone and 4% bagasse ash; vi. 8%M+6%Ca+6%Ba means: test tubes made by the soil with 8% molasses, 6% limestone and 6% bagasse ash; vii. 8%M+8%Ca+8%Ba means: test tubes made by the ground with 8% molasses, 8% limestone and 8% bagasse ash.

Drying, pressing and pulling briquettes: The samples were dried in a UNICOM laboratory room in the open air at room temperature for 28 days (Figure-2). Mechanical tests are carried out on days 7, 21 and 28. Water absorption tests are carried out after 28 days of age of the specimens.



Figure-2: Samples of bricks manufactured.

Compressive and tensile strengths: Mechanical tests are carried out on the bricks after 7 days, 21 days and 28 days respectively.



Figure-3: Apparatus used for mechanical resistances.

Water Absorption Coefficient (C): We calculate the average of three results. The coefficient C, of water absorption of each specimen is expressed by the formula¹⁰:

$$C = \frac{100M}{s\sqrt{t}}\%$$

with: M = mass of water (in g) absorbed by the specimen, s = product of the length by the width of the submerged face, expressed in square centimetres, t = time (in minutes) elapsed since the beginning of the capillary rise.

Porosity: Porosity is a quantity that gives indications of the voids contained in the material. It is calculated as follows:

$$N = \frac{V_v}{V_t} \times 100 \%$$

$$V_v = V_e - \frac{m_e}{a_e} = m_e = P_h - P_s,$$

With: V_v : Volume of Voids, V_t : Total sample volume, V_e : Volume of water, m_e : body of water, P_h : wet weight, P_s : Dry Weight, $a_e = 1\text{g/cm}^3$: density of water.

Linear Indent: After the samples were made, the length of each was measured using a caliper while the length variation is determined by the formula:

$$R = \frac{L_0 - L_t}{L_0}$$

With: L_0 : length of the specimen on the first day of manufacture, L_t : length of the specimen after a given time.

Absolute Density of Bricks: The density of each sample is determined by the following formula:

$$d = \frac{a}{a_e} \text{ et } a = \frac{m}{V}, V = L \times l \times l'$$

With: d: density of the specimen, a: Density of the sample (g/cm^3), a_e : density of water (1g/cm^3), m: mass of the sample, V: sample volume, L; Specimen length, l: width of the specimen, l': height of the specimen.

Results and Discussion

Geotechnical characteristics of the soil used. All the results of the soil identification tests are presented in Table-4. According to the GTR classification (Guide des Terrassements Routiers) the samples taken are clay soils (fine soils of class A1), so our sample is clay. However, its fines content is very high ($\% 80\mu\text{m} = 88.95$). The plasticity index is equal to 32.6%, plastic materials have a plasticity index between 15 and 40%. The maximum optimum proctor is 22.5% corresponding to very plastic clays (about 20 to 30% m of water). These are plastic soils and very sensitive to water because their consistency changes abruptly according to variations in water content¹¹.

Table-4: Results of the geotechnical characteristics of the soil.

Profondeur (cm)	Granulometry	Atterberg limits		Compactibility		Methylene blue	
	% < 80 μm	Wl (%)	Wp (%)	Ip (%)	d (g/cm ³)	W ^o (OP M)	VBS (g/100 g)
-50	88.95	59.2	26.6	32.6	1.65	22.5	0.34

Mechanical Compressive Strength: Compressive Strength of specimens made from molasses and limestone: Samples stabilized at 8% molasses, 8% molasses +4% limestone and 8% molasses + 6% limestone show similar compressive strengths at young ages (7th and 21st days): on the 7th day, 1.9 MPa for the control sample (8% molasses), 3.8 MPa for the stabilized sample with 8% molasses + 4% limestone, 3.975 MPa for the 8% molasses+6% limestone stabilized sample, 3.8 MPa for the

8%+8% limestone stabilized sample. On day 21, 1.95 MPa for the control sample, 3.9 MPa for the stabilized sample at 8% molasses+4% limestone, 4 MPa for the stabilized sample at 8% molasses +6% limestone, 4 MPa for the stabilized sample at 8% molasses+8% limestone. On day 28, there was an increase in compressive strength for the stabilized samples from 8% molasses + 8% limestone (4.65 MPa), then there was no change for the stabilized sample at 8% molasses+4% limestone and 8% molasses+6% limestone except for the control sample. All samples containing limestone have very high compressive strengths compared to the reference sample (8% molasses) as shown in Figure-4.

This increase in strength is due to the presence of calcium in limestone, as limestone in solution releases Ca^{++} ions and CO_3^{-2} ions. According to Hora, the strength properties of the material are essentially the result of a dissolution of clay minerals in an alkaline environment produced by calcium and the recombination of silica and alumina of clays with calcium to form complex silicates of aluminum and calcium that cement the grains together¹. This cementation is more considered in the stabilized sample at 8% molasses + 8% limestone. The results obtained reveal interesting mechanical compressive strengths for all formulations made from molasses and limestone. It is found that the compressive strength values are greater than 2MPa, according to the standards XP P 13-901 (France), ASTM E2392-10 (America), NBR (Brazil) the trend is towards a minimum compressive strength requirement of 2MPa after 28 days of age so that the blocks are usable for construction¹¹.

Compressive strengths of specimens stabilized by molasses and bagasse ash: The compressive strengths of specimens made from molasses and bagasse ash have lower strengths compared to reference samples. On day 7, 1.9 MPa for samples stabilized at 8% molasses+4% bagasse ash, 1.9 MPa for samples stabilized at 8% molasses+6% bagasses ash, 1.95 MPa for samples stabilized at 8% molasses+8% bagasses ash. On day 21, 1.9 MPa for samples stabilized at 8% molasses+4% bagasse ash, 1.85 MPa for samples stabilized at 8% molasses+6% bagasses ash, 1.9 MPa for samples stabilized at 8% molasses+8% bagasses ash. On day 28, 1.95 MPa for samples stabilized at 8% molasses+4% bagasse ash, 1.75 MPa for samples stabilized at 8% molasses+6% bagasse ash, 1.65 MPa for samples stabilized at 8% molasses+8% bagasses ash. It can be seen that the resistance of the sample stabilized by 8% molasses and 6% bagasse ash decreases by 0.10 MPa compared to that of the 21st day. The strength of the sample stabilized by 8% molasses and 8% bagasse ash decreased by 0.25 MPa on day 28 compared to that on day 21.

From 6% bagasse ash, the addition of bagasse ash over time decreases the resistance of a soil stabilized by sugar cane molasses. On day 28, specimens made of 8% molasses + 6% bagasse ash and 8% molasses + 8% bagasses ash give lower resistances compared to the control sample (Figure-5).

This proves that sugarcane bagasse ash decreases the compressive strength of a soil stabilized with molasses. This decrease in strength may be due to the weak cohesion between the oxides produced by bagasse ash, the organic matter of sugarcane molasses and clay minerals. As noted, several research studies have been carried out in the context of soil stabilization by a binder. Mango Itulamya, incorporating bagasse ash and lime into the soil. He showed that bagasse ash combined with lime does not increase the compressive strength of the material¹². This is because the ash obtained contains little amorphous silica. It is therefore not very pozzolanic and then interacts as a simple physical stabilizer. The results obtained reveal that mechanical compressive strengths are less than 2 MPa for all formulations made from molasses and bagasse ash. According to XP P 13-901 (France), ASTM E2392-10 (America), NBR (Brazil) the trend is towards a minimum compressive strength requirement of 2MPa¹¹, so that the blocks can be used for construction. Therefore, all formulations made with molasses and bagasse ash do not meet the standards. All these results show that limestone appears to be an important adjuvant in the optimization of formulations and consequently, it contributes to improving the mechanical performance of clay soil stabilized with sugar cane molasses. Comparing with a number of works such as: i. Malanda et al showed that sugarcane molasses incorporated in clay, for a percentage of 12% molasses, made it possible to achieve compressive strengths of the order of 4.65MPa and tensile strengths of the order of 1.10 MPa, improves the mechanical properties of the stabilized brick². ii. Abakar Ali proved that gum arabic added to clay soil, improves mechanical strength by 1.5 to 15%, achieves compressive strengths of the order of 0.45 to 0.974MPa while rice straw with a dosage that varies between 0.5 to 1.5% decreases mechanical strengths¹³. iii. Gheddache Hora showed that cement and lime in the dry state incorporated at 4% in the clay soil, increase in mechanical strength with values of 6.3MPa and 4.3MPa respectively¹.

It can be noted that our mechanical results are inferior compared to Gheddache's studies, of course; but significantly compliant with the standards laid down by CRA-terre. On the other hand, the results obtained are equivalent to those obtained by Malanda and better than those obtained by Abakar.

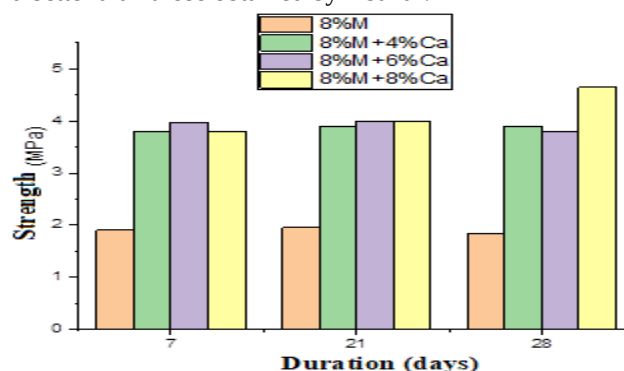


Figure-4: Compressive strengths of specimens made from molasses and limestone.

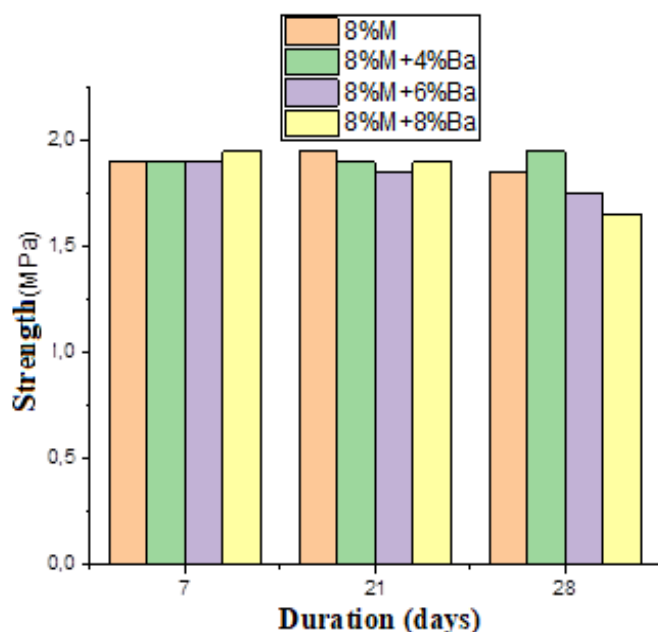


Figure-5: Compressive strengths of specimens made by molasses and bagasse ash.

Mechanical compressive strength of samples stabilized with molasses, limestone and bagasse ash: Samples stabilized by molasses, limestone and bagasse ash show similar resistance from young age (day 7) to day 28 (Figure-6). On the 7th day, 1.9 MPa for reference samples, 1.65 MPa for samples stabilized at 8% molasses+4% limestone+4% bagasse ash, 1.5 MPa for samples stabilized at 8% molasses+6% limestone+6% bagasse ash, 1.95 MPa for stabilized samples at 8% molasses +8% limestone+8% bagasse ash. On day 21, 1.75 MPa for samples stabilized at 8% molasses+4% limestone+4% bagasse ash, 1.6 MPa for samples stabilized at 8% molasses+6% limestone+6% bagasse ash, 2 MPa for samples stabilized at 8% molasses+8% limestone+8% bagasse ash. On day 28, 2 MPa for samples stabilized at 8% molasses+4% limestone+4% bagasse ash, 1.8 MPa for samples stabilized at 8% molasses+6% limestone+6% bagasse ash, and 2 MPa for samples stabilized at 8% molasses+8% limestone+8% bagasse ash. There is a decrease in compressive strength compared to samples stabilized by molasses and limestone.

This decrease in strength may be due to the influence of bagasse ash oxides that prevent the strength properties of the material resulting in the dissolution of clay minerals in an alkaline environment produced by calcium and the recombination of silica and alumina of clays with calcium to form complex aluminum and calcium silicates that cement the grains together. This same observation is observed by Mango-Itulamy, which stabilized the soil with cement and bagasse ash. He found that the increase in bagasse ash decreased the strength of the samples¹². The organic matter in sugarcane molasses has no influence on this reaction.

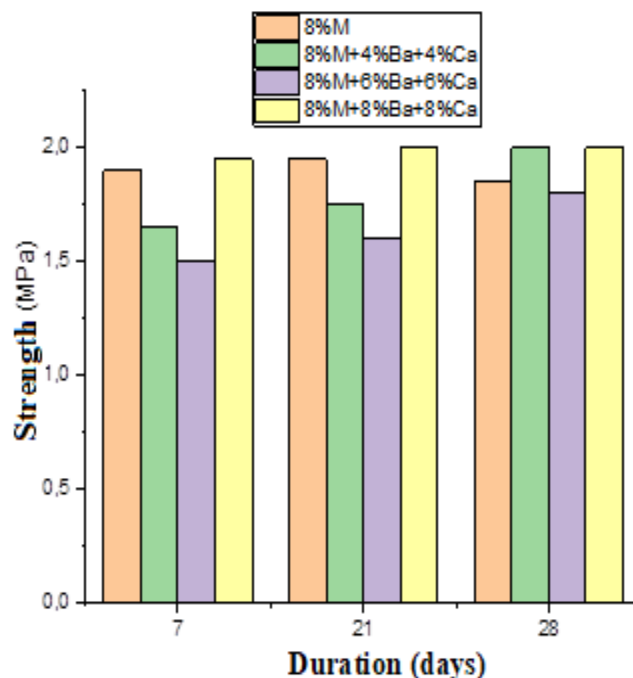


Figure-6: Compressive strength of specimens made from molasses, limestone and bagasse ash.

Mechanical tensile strength: Tensile strengths of specimens stabilized with molasses and limestone: The tensile strengths of the specimens manufactured for the molasses and limestone combination increase on the 28th day. On the 7th day, 0.5 MPa for reference samples, 0.7 MPa for samples stabilized at 8% molasses+4% limestone, 0.7 MPa for samples stabilized at 8% molasses+6% limestone, and 0.8 MPa for samples stabilized with 8% molasses+8% limestone.

On day 21, 0.8 MPa for control samples, 0.7 MPa for samples stabilized at 8% molasses + 4% limestone, 0.7 MPa for samples stabilized at 8% molasses + 6% limestone, 1 MPa for samples stabilized at 8% molasses + 8% limestone. On day 28, 0.8 MPa for control samples, 0.8 MPa for samples stabilized at 8% molasses + 4% limestone, 0.9 MPa for samples stabilized at 8% molasses + 6% limestone, 1.2 MPa for stabilized samples at 8% molasses + 8% limestone (Figure 7). It can be seen that at a young age, the tensile strength is the same with the exception of samples stabilized at 8% molasses + 8% limestone.

There is an increase in tensile strength for samples stabilized at 8% molasses + 8% limestone. The tensile strength results are in agreement with the compressive strength results. Thus, the increase in strength is due to the properties of the material resulting essentially from the dissolution of clay minerals in an alkaline environment produced by calcium and the recombination of silica and alumina of clays with calcium to form complex silicates of aluminum and calcium that cement the grains together¹.

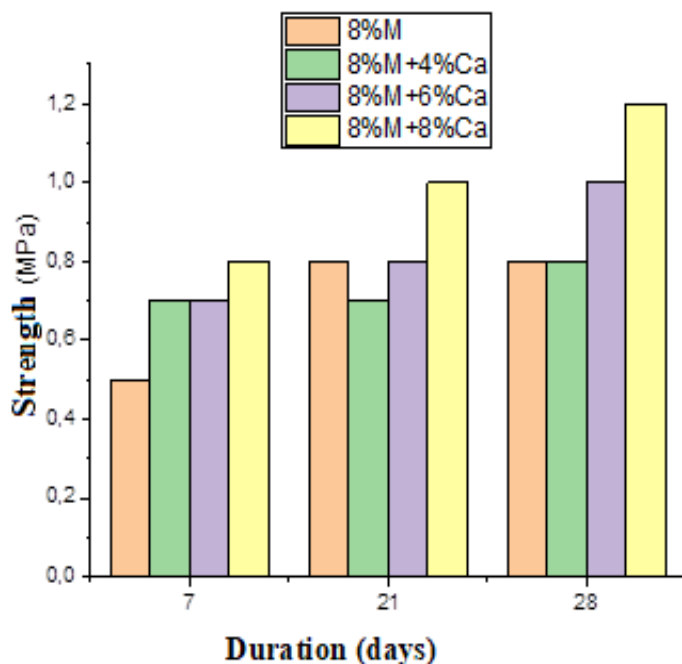


Figure-7: Tensile strength of specimens made from molasses and limestone.

Tensile strengths of samples stabilized with molasses and bagasse ash:

The mechanical tensile strengths of the specimens manufactured for the molasses and bagasse ash assembly show high tensile strengths on day 21. However, they decreased on day 28 with the exception of the sample stabilized by 8% molasses and 4% bagasse ash, whose resistance increased with time. On day 7, 0.7 MPa for samples stabilized at 8% molasses + 4% bagasse ash, 0.6 MPa for samples stabilized at 8% molasses + 6% bagasses ash and 0.6 MPa for samples stabilized at 8% molasses + 8% bagasses ash. On day 21, 0.8 MPa for samples stabilized at 8% molasses + 4% bagasse ash, 0.7 MPa for samples stabilized at 8% molasses + 6% bagasses ash and 0.8 MPa for samples stabilized at 8% molasses + 8% bagasses ash. On day 28, 0.8 MPa for samples stabilized at 8% molasses+4% ash, 0.6 MPa for samples stabilized at 8% molasses+6% ash, and 0.6 MPa for samples stabilized at 8% molasses+8% bagasses ash (Figure 8). The strength of the sample stabilized by 8% molasses and 6% bagasse ash decreased by 0.10 MPa compared to the resistance of the 21st day and that of the sample stabilized by 8% molasses and 8% bagasse ash decreased by 0.20 MPa by the 28th day compared to the resistance of the 21st day. From 6% bagasse ash, the addition of bagasse ash over time reduces the resistance of a soil stabilized by sugar cane molasses. On day 28, specimens made of 8% molasses + 6% bagasse ash and 8% molasses + 8% ash give lower resistances compared to the control sample. This proves that sugarcane bagasse ash decreases the tensile strength of soil stabilized with molasses. Nevertheless, the optimal percentage of bagasse ash is 4% when it comes to tensile strength.

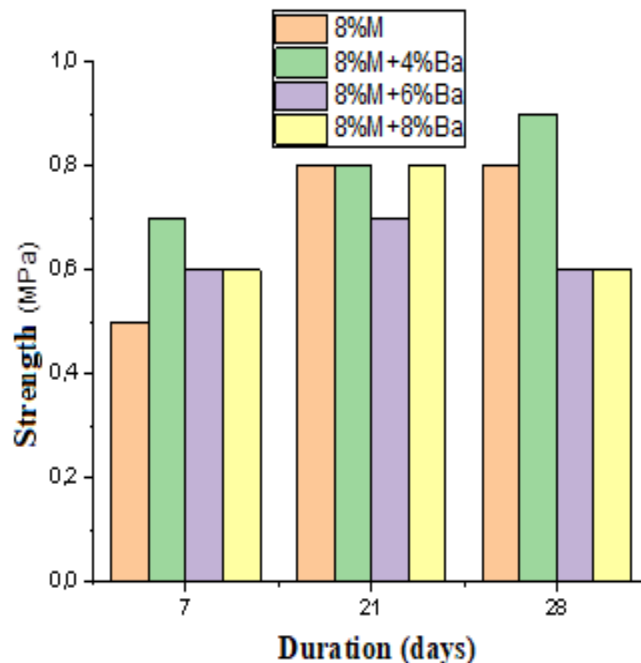


Figure-8: Tensile strength of samples stabilized with molasses and bagasse ash.

Tensile strength of specimens stabilized with molasses, limestone and bagasse ash:

The tensile strengths of specimens manufactured for the combination of molasses, limestone and bagasse ash increase with time until the 28th day. On day 7, 0.6 MPa for samples stabilized at 8% molasses+4% limestone+4% bagasse ash, 0.5 MPa for samples stabilized at 8% molasses+6% limestone+6% bagasse ash, and 0.7 MPa for samples stabilized at 8% molasses+8% limestone+8% bagasse ash. On day 21, 0.7 MPa for samples stabilized at 8% molasses+4% limestone+4% bagasse ash, 0.6 MPa for samples stabilized at 8% molasses+6% limestone+6% bagasse ash, 0.8 MPa for samples stabilized at 8% molasses+8% limestone+8% bagasse ash. On day 28, 0.9 MPa for samples stabilized at 8% molasses + 4% limestone + 4% bagasse ash, 0.8 MPa for samples stabilized at 8% molasses + 6% limestone + 6% bagasse ash, 0.9 MPa for samples stabilized at 8% molasses + 8% limestone + 8% bagasse ash (Figure-9). These tensile strengths of the stabilized samples for the molasses, limestone and bagasse ash ensemble are identical to the tensile strengths of the stabilized samples for the molasses and limestone ensemble with the exception of the samples stabilized at 8% molasses + 8% limestone. From 8% bagasse ash, there is a weak cohesion between the calcium ions released by the limestone, clay minerals, organic substances from sugarcane molasses and the oxides produced by bagasse ash. As Mango Itulamya found in 2017, by incorporating bagasse ash into lime¹². He showed that bagasse ash combined with lime does not sufficiently increase the strength of the material. This is because the ash obtained contains little amorphous silica. It is therefore not very pozzolanic and then interacts as a simple physical stabilizer.

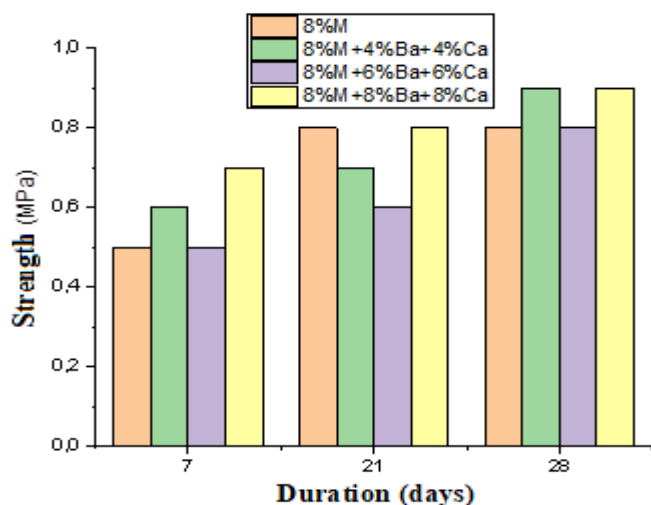


Figure-9: Tensile strength of specimens made of molasses, limestone and bagasse ash.

Water Absorption: Water Absorption of samples stabilized with molasses and limestone: Samples stabilized by molasses and limestone have lower percentages of water absorption than the control sample. 5.27% for the reference samples, 4.68% for the samples stabilized at 8% molasses + 4% limestone, 2.96% for the stabilized samples at 8% molasses + 6% limestone and 3.16% for the stabilized samples at 8% molasses + 8% limestone (Figure-10). Limestone in solution releases calcium ions (Ca^{++}) and carbonate ions (CO_3^{2-}). This decrease in water absorption by all samples stabilized by molasses and limestone is due to the flocculating power of calcium ions (Ca^{++}) on mineral and organic colloids. They also have an aggregating power by establishing links between organic colloids and minerals. Therefore, the Ca^{++} ions create cohesion between the particles of the earth and the molasses. These established links create a reduction in micropores and mesopores detected by Ngouallat in 2022, for a clay soil stabilized by sugarcane molasses².

Water absorption of specimens stabilized with molasses, limestone and bagasse ash: Except for the samples stabilized with 8% molasses + 4% limestone + 4% bagasse ash, the samples stabilized by the molasses, limestone and bagasse ash ensemble have lower water absorption percentages compared to the control sample. 7.34% for samples stabilized with 8% molasses+4% limestone+4% bagasse ash, 3.88% for samples stabilized with 8% molasses+6% limestone+6% bagasse ash, 4.40% for stabilized samples with 8% molasses+8% limestone+8% bagasse ash (Figure-11). From 6% bagasse ash, there is good cohesion with the clay soil stabilized by molasses and limestone for pore reduction. The oxides contained in this ash react with the limestone, providing a reduction in absorption thanks to the flocculating power of calcium ions (Ca^{++}) on the mineral and organic colloids. These established links create a reduction in micropores and mesopores detected by Ngouallat in 2022, for a clay soil stabilized by sugarcane molasses².

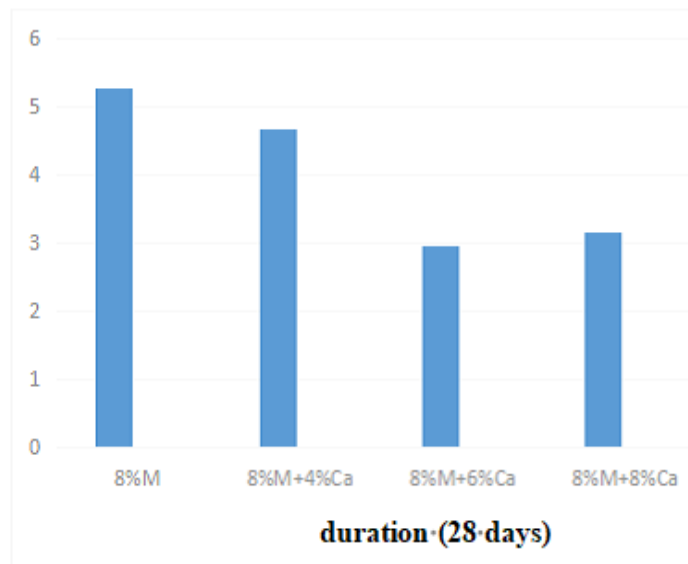


Figure-10: Water uptake as a percentage of samples stabilized using molasses and limestone.

Percentage of water absorption of test tubes stabilized by molasses and sugarcane bagasse ash: With the exception of samples stabilized at 8% molasses + 4% bagasse ash, samples stabilized by molasses and bagasse ash have lower percentages of water absorption than the reference sample. 5.95% for samples stabilized at 8% molasses+4% bagasse ash, 3.58% for samples stabilized at 8% molasses+6% limestone ash, 4.87% for stabilized samples at 8% molasses+8% bagasses ash (Figure 12). The oxides formed by bagasse ash create bonds on the mineral and organic colloids of the earth and molasses. These bonds form a cohesion that causes the pores to close and shrink.

Porosity: Porosity of samples stabilized by molasses and limestone: Samples stabilized by molasses and limestone have a low porosity compared to the reference sample. 6.75% for the control sample, 7.62% for samples stabilized with 8% molasses+4% limestone, 4.47% for samples stabilized with 8% molasses+6% limestone, and 4.53% for samples stabilized with 8% molasses+8% limestone (Figure-13). Limestone contributes to the reduction of pores in soil stabilized by sugarcane molasses. When calcium-rich minerals are added to moistened soil, it becomes saturated with calcium ions. A phenomenon of cation exchange then appears: calcium ions replace the exchangeable cations of the earth complex such as magnesium, sodium, potassium and hydrogen.

The magnitude of this cation exchange depends on the amount of exchangeable cations present in the total cation exchange capacity of the earth. This exchange creates the recombination of silica and alumina in the clays with calcium to form complex aluminum-calcium silicates that cement the grains together¹. This cementation is the cause of the pore closure. This is more observed by the addition of 6% limestone in soil stabilized with molasses.

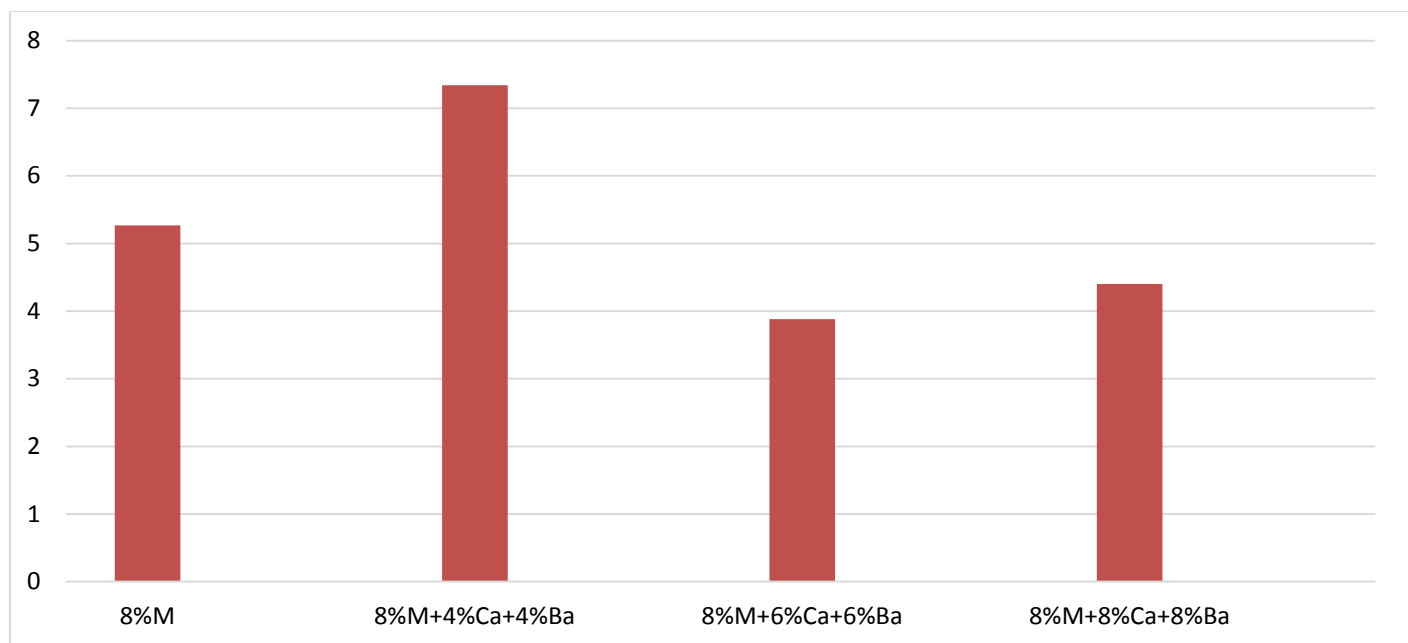


Figure-11: Water Absorption of Stabilized Samples Using Molasses, Limestone, and Bagasse Ash.

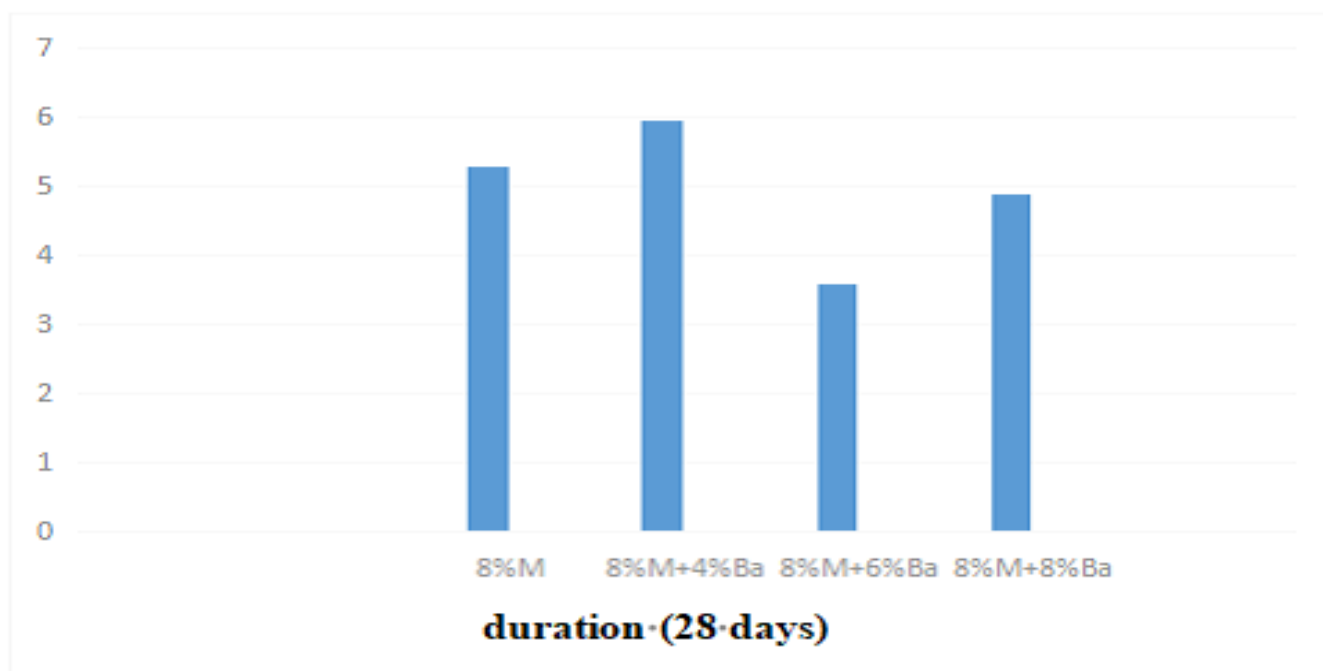


Figure-12: Water absorption of samples stabilized by molasses and sugarcane bagasse ash.

Porosity of samples stabilized by molasses and bagasse ash:

Samples stabilized with molasses and bagasse ash have a lower porosity compared to the reference samples and with the exception of samples stabilized at 8% molasses+4% bagasse ash. 6.75% for control samples, 7.62% for samples stabilized at 8% molasses+4% bagasse ash, 4.56% for samples stabilized at 8% molasses+6% ash, 6.23% for stabilized samples at 8% molasses+8% bagasses ash (Figure-14). The low porosity of the

samples stabilized at 8% molasses + 6% bagasse ash is due to the reduction of mesopores or even the removal of micropores detected by Nice Ngouallat in 2022 which stabilized the soil with sugar cane molasses². At 8% molasses + 6% bagasse ash, there is a good coalition between the oxides formed by bagasse ash and the mineral and organic colloids of the soil and molasses. The porosity results are in agreement with the results of the percentage of water absorption.

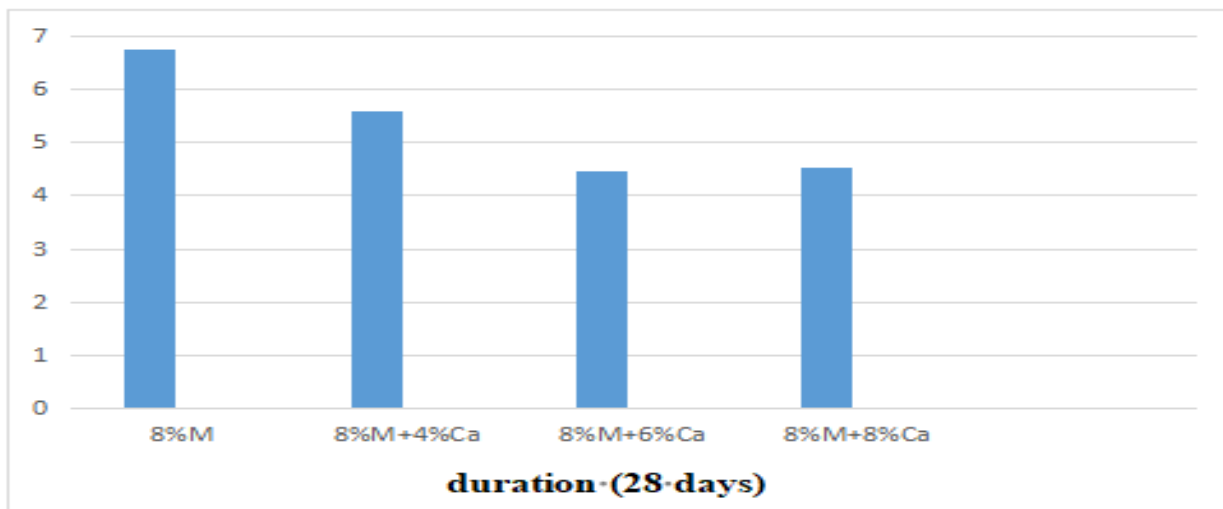


Figure-13: Porosity of molasses and limestone-stabilized samples.

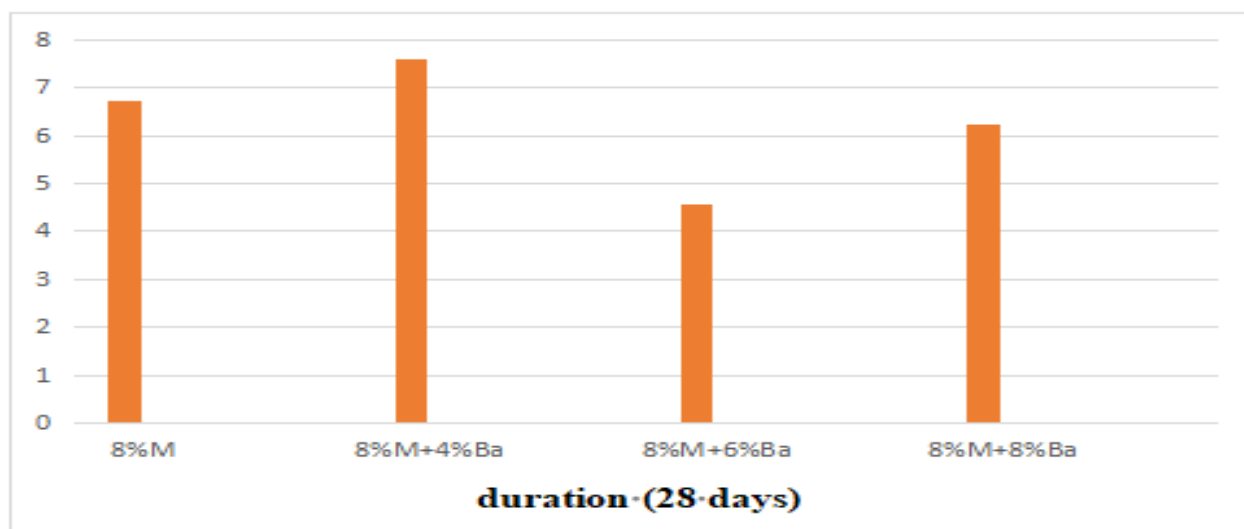


Figure-14: Porosity of samples stabilized using molasses and bagasse.

Porosity of samples stabilized by molasses, limestone and bagasse ash: Samples stabilized by molasses, limestone and bagasse ash have a lower porosity compared to the reference sample and with the exception of samples stabilized by 8% molasses+4% limestone+4% bagasse ash. 6.75% for the reference sample, 9.38% for samples stabilized by 8% molasses+4% limestone+4% ash, 4.96% for samples stabilized by 8% molasses+6% limestone+6% ash, and 5.65% for samples stabilized by 8% molasses+8% limestone+8% bagasse ash (Figure-15). The addition of 6% limestone and 6% bagasse ash influences the porosity of the soil stabilized with molasses, on the other hand 4% limestone and 4% ash create even more pores. The same is true for samples stabilized by molasses and bagasse ash. This analysis shows that bagasse ash has a greater influence than limestone on clay soil stabilized with molasses. These results are in agreement with the results of water absorption, compressive strengths, and tensile strengths.

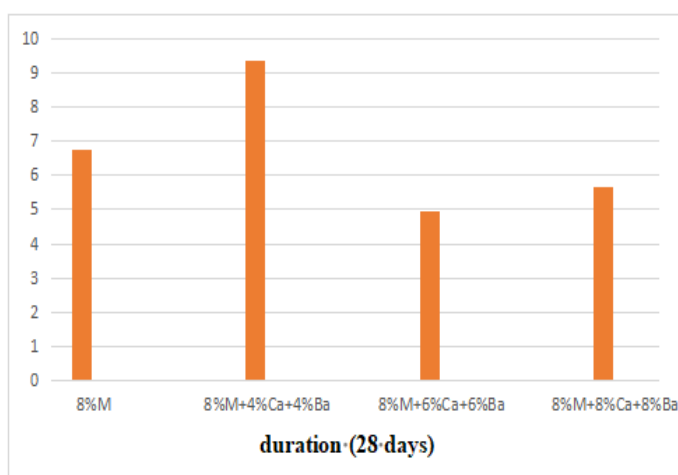


Figure-15: Porosity of samples stabilized by molasses, limestone and bagasse ash.

Linear Indent: Variation in the length of specimens made by molasses and limestone: The length of specimens made from limestone decreases with time, which causes linear shrinkage to increase. On day 7, the reference sample at a linear shrinkage of 5.52%, the stabilized sample at 8% molasses and 4% limestone has a shrinkage of 3.62%, the stabilized sample at 8% molasses and 6% limestone has a shrinkage of 2.84%, the stabilized sample at 8% molasses and 8% limestone has a shrinkage of 2.02%. On day 14, the control sample has a shrinkage of 5.68%, the 8% molasses and 4% limestone stabilized sample has a shrinkage of 3.63%, the 8% molasses and 6% limestone stabilized sample has a shrinkage of 2.90%, the 8% molasses and 8% limestone stabilized sample has a shrinkage of 2.52%. On day 21, the reference sample at a shrinkage of 5.81%, the stabilized sample at 8% molasses and 4% limestone has a shrinkage of 4.55%, the stabilized sample at 8% molasses and 6% limestone has a shrinkage of 3.9%, and the stabilized sample at 8% molasses and 8% limestone has a shrinkage of 3.8%. On day 28, the reference sample at a shrinkage of 5.89%, the stabilized sample at 8% molasses and 4% limestone has a shrinkage of 4.60%, the stabilized sample, the stabilized sample at 8% molasses and 6% limestone has a shrinkage of 4.52%, and the stabilized sample at 8% molasses and 8% limestone has a shrinkage of 3.97% (Figure 16). All molasses- and limestone-stabilized samples have a lower linear shrinkage compared to the reference sample. The addition of limescale decreases the linear shrinkage of the material; This may be due to its calcium power. According to the standard, the withdrawal percentage should be less than 8%. All these samples obey the standard.

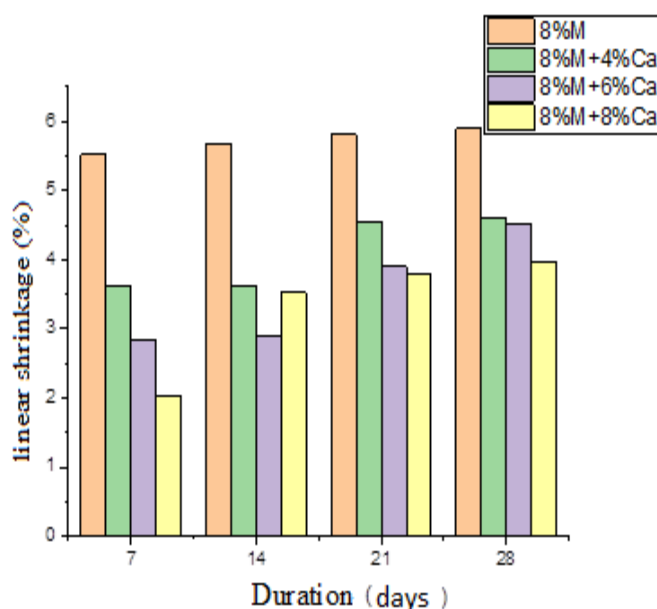


Figure-16: Variation in the length of specimens made by molasses and limestone.

Variation in the length of specimens made by molasses, limestone and bagasse ash: The length of specimens made by molasses, limestone and bagasse ash decreases with time. On

the 7th day, the stabilized sample at 8% molasses+4% limestone+4% bagasse ash has a shrinkage of 3.32%, the stabilized sample at 8% molasses+6% limestone+6% ash has a shrinkage of 3.92%, the stabilized sample at 8% molasses+8% limestone+8% ash has a shrinkage of 4.03%. On the 14th day, 3.82% for a stabilized sample at 8% molasses+4% limestone+4% ash, 4.02% for a stabilized sample at 8% molasses+6% limestone+6% ash, and 4.07% for a stabilized sample at 8% molasses+8% limestone+8% ash. On the 21st day, 3.87% for the sample stabilized by 8% molasses+4% limestone+4% ash, 4.10% for the sample stabilized by 8% molasses + 6% limestone + 6% ash and 4.11% for the sample stabilized by 8% molasses + 8% limestone + 8% ash. On the 28th day, 4.28% for the sample stabilized by 8% molasses+4% limestone+4% ash, 4.24% for the sample stabilized by 8% molasses+6% limestone+6% ash, and 4.28% for the sample stabilized by 8% molasses+8% limestone + 8% ash (Figure-17). All these samples show a very low shrinkage compared to the reference sample. Limestone and sugarcane bagasse ash contribute to and prevent the rapid decrease in the length of the specimens.

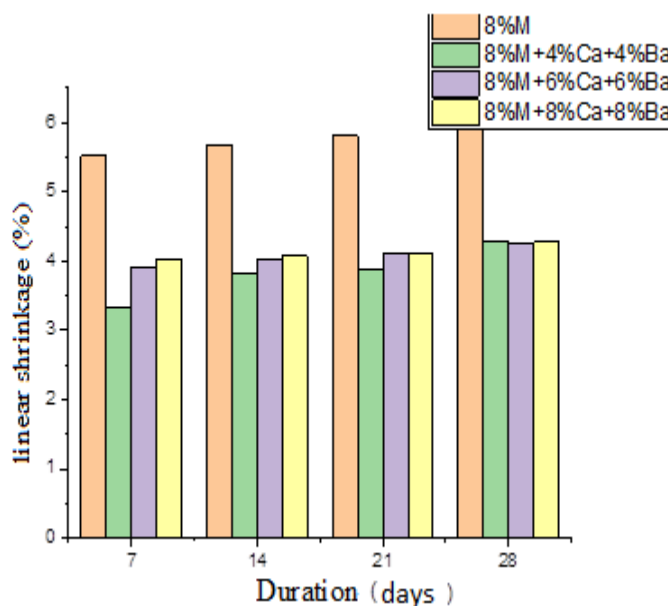


Figure-17: Linear shrinkage of samples stabilized by molasses, limestone and bagasse ash.

Variation in the length of specimens made by molasses and bagasse ash: The length of the test tubes made by molasses and bagasse ash decreases with time, hence the increase in the shrinkage percentage. On the 7th day, 3.36% for the sample stabilized by 8% molasses + 4% ash, 4.21% for a sample stabilized by 8% molasses + 6% ash and 4.21% for a sample stabilized by 8% molasses and 8% ash. On the 14th day, 4.76% for a sample stabilized by 8% molasses+4% ash, 4.24% for a sample stabilized by 8% molasses+6% ash, and 4.32% for the sample stabilized by 8% molasses+8% ash. On day 21, 4.88% for a sample stabilized with 8% molasses + 4% ash, 4.53% for a sample stabilized with 8% molasses + 6% ash and 4.39% for the

sample stabilized with 8% molasses and 8% ash. On day 28, 5.16% for the sample stabilized with 8% molasses and 4% ash, 4.68% for the sample stabilized with 8% molasses and 6% ash, and 4.43% for a sample stabilized with 8% molasses and 8% ash (Figure 18). Bagasse ash decreases the percentage of shrinkage of a material made by sugarcane molasses.

Measuring density variation: Variation in density of specimens made by molasses and limestone: Specimens made from limestone show almost similar densities from young age to day 28. On day 14, 2.169 for the reference sample, 2.242 for the sample stabilized with 8% molasses and 4% limestone, 2.249 for the sample stabilized with 8% molasses and 6% limestone, 2.240 for the sample stabilized with 8% molasses and 8% limestone. On day 21, 2.126 for the 8% molasses stabilized sample, 2.245 for the 8% molasses+4% limestone stabilized sample, 2.372 for the 8%+6% limestone stabilized sample, and 2.219 for the 8% molasses+8% limestone stabilized sample. On day 28, 2.065 for the reference sample, 2.084 for the 8% molasses + 4% limestone stabilized sample, 2.053 for the 8% molasses + 6% limestone stabilized sample, 2.045 for the 8% molasses + 8% limestone stabilized sample (Figure 19). After 28 days of age, the higher the level of adjuvants, the more the density decreases. Sugarcane molasses with a density of 1.39. Calcite has a density ranging from 2.6 to 2.8¹⁴. The density of the soil is higher than the density of admixtures such as limestone and molasses. The addition of these admixtures to the soil influences and decreases the density of the soil, hence the appearance of materials with a density of less than 2.6.

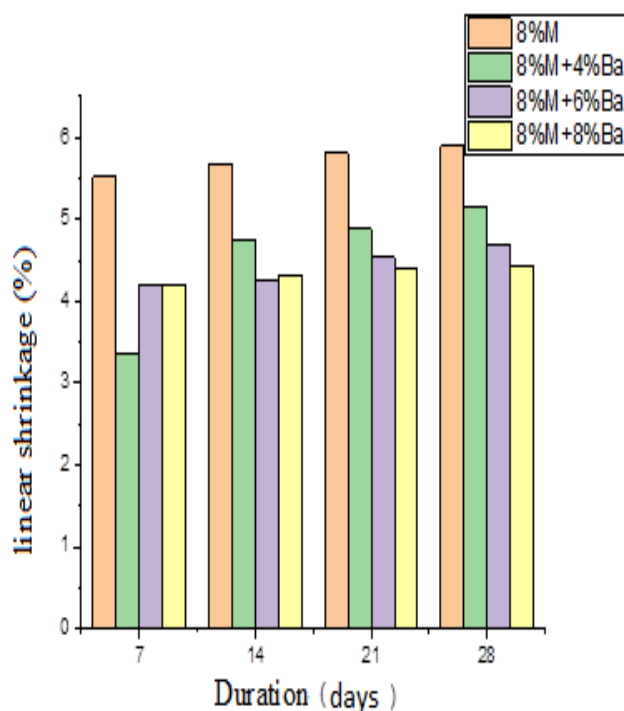


Figure-18: Linear shrinkage of molasses and bagasse ash stabilized samples.

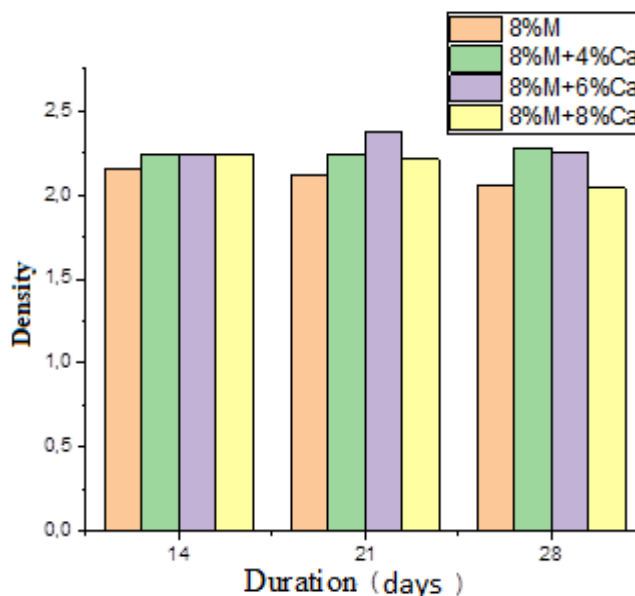


Figure-19: Density of samples stabilized by molasses and limestone.

Variation in density of specimens made by molasses, limestone and bagasse ash: Samples made by all molasses, limestone and bagasse ash show similar density values from young age to day 28. On the 14th day, 2.089 for the sample stabilized by 8% molasses+4% limestone+4% ash, 2.168 for the sample stabilized by 8% molasses+6% limestone+6% ash, 2.155 for the sample stabilized by 8% molasses+8% limestone+8% ash. On the 21st day, 2.097 for the sample stabilized by 8% molasses+4% limestone+4% ash, 2.117 for the sample stabilized by 8% molasses+6% limestone+6% ash, 2.091 for the sample stabilized by 8% molasses+8% limestone+8% ash. On the 28th day, 2.049 for the sample stabilized by 8% molasses+4% limestone+4% ash, 2.094 for the sample stabilized by 8% molasses+6% limestone+6% ash and 2.111 for the sample stabilized by 8% molasses+8% limestone+8% bagasse ash (Figure 20). After 28 days of age, the higher the rate of admixtures, the more the density of the materials increases slightly. Sugarcane molasses with a density of about 1390 kg/m³ with a density of 1.39¹⁴. Bagasse ash with a very low density in relation to the soil, molasses and limestone. The cohesion of admixtures such as molasses, limestone, and bagasse ash in the soil results in materials with a density lower than the density of soil and calcite. The density of these materials varies slightly depending on the amount of admixtures after 28 days, as shown in Figure-20.

Variation in density of specimens made by molasses and bagasse ash: The specimens manufactured have similar density values from young age to day 28. On day 14, 2.14 for samples stabilized at 8% molasses+4% bagasse ash, 2.14 for samples stabilized at 8% molasses+6% badasses ash, and 2.12 for samples stabilized at 8% molasses+8% ash. On day 21, 2.16 for samples stabilized at 8% molasses+4% ash, 2.078 for samples

stabilized at 8% molasses+6% ash, and 2.10 for samples stabilized at 8% molasses+8% bagasses ash. On day 28, 2.13 for samples stabilized at 8% molasses+4% ash, 2.08 for samples stabilized at 8% molasses+6% bagasse, and 2.07 for samples stabilized at 8% molasses+8% bagasses ash (Figure 21). Between day 14 and day 21, the reference samples showed almost similar densities with the samples stabilized at 8% molasses + 4% bagasse ash. After 28 days of age, as shown in Figure 21, the higher the level of bagasse ash, the lower the density of the materials. This decrease in density may be due to the low density of bagasse ash. This ash and molasses incorporated into the soil decreases the density of the soil, hence the presence of materials whose density is lower than that of the soil.

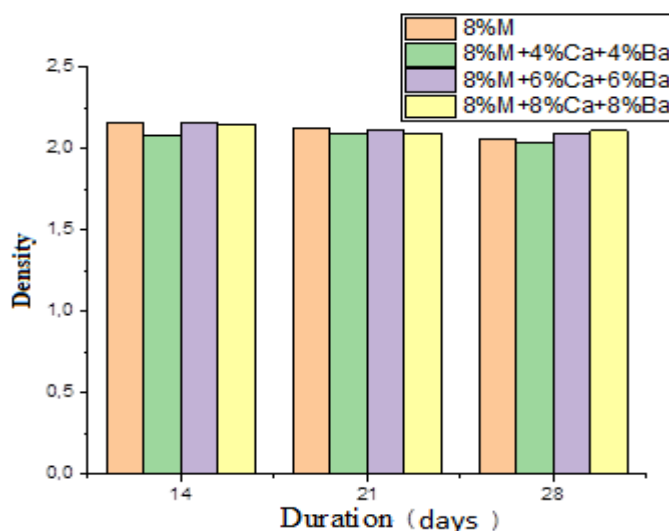


Figure-20: Density of samples stabilized by molasses, limestone and bagasse ash.

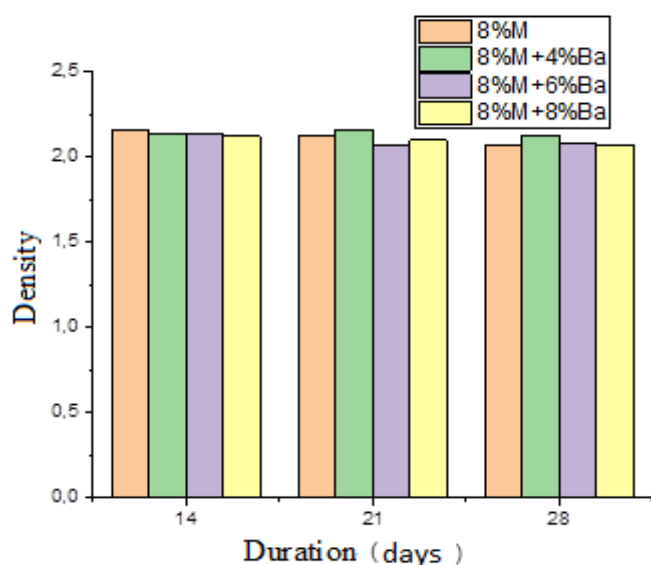


Figure-21: Density of samples stabilized by molasses and bagasse ash.

Conclusion

This study reveals that: i. Mechanical compressive and tensile strengths are interesting for all formulations made from molasses and limestone. the percentage of 8% limestone gives more gain in compressive strength (4.65 MPa) and tensile strength (1.2 MPa) in soil stabilized at 8% sugarcane molasses; ii. The addition of bagasse ash does not provide any gains in compressive and tensile strength in soil stabilized at 8% sugarcane molasses. The optimal percentage of bagasse ash is 4%, iii. the combination of bagasse ash (8%) and limestone (8%) slightly increases the compressive (2 MPa) and tensile strength (0.9 MPa) of the stabilized soil at 8% sugarcane molasses (compression (1.85 MPa), tensile (0.8 MPa). However, there is a decrease in compressive and tensile strength compared to molasses and limestone stabilized samples, iv. the addition of 6% limestone reduces water absorption (2.96%) in soil stabilized by 8% sugar cane molasses (5.27%), v. the addition of 6% sugarcane bagasse ash contributes to the reduction of water absorption (3.58%) of the stabilized clay soil to 8% sugar cane molasses (5.27%), vi. the combination of bagasse ash (6%) and limestone (6%) does not reduce water absorption. vii. the addition of limestone (6%) reduces the porosity (4.47%) of the clay soil stabilized to 8% sugar cane molasses (6.75%), viii. the addition of bagasse ash (6%) reduces the porosity (4.56%) of the clay soil stabilized to 8% sugar cane molasses (6.75%), ix. the combination of bagasse ash (6%) and limestone (6%) reduces the porosity (4.96%) of the clay soil stabilized at 8% sugar cane molasses (6.75%), x. The addition of limestone alone and bagasse ash alone to the clay soil stabilized at 8% sugar cane molasses does not improve its density. xi. The combination of bagasse ash and limestone slightly improves the density of the clay soil stabilized at 8% sugar cane molasses.

We can say that the combination of sugar cane molasses and limestone improves the physico-mechanical properties of the soil stabilized by sugar cane molasses. Sugarcane bagasse ash must be added through limestone to stabilize clay soil using molasses.

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