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RESEARCH ARTICLE

INFLUENCE OF CANE MOLASSES ON PLASTICTY OF EXPANSIVE CLAY SOIL

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ABSTRACT

This paper investigates the influence of molasses in reducing the plasticity of expansive clay soil. Plasticity tests of untreated soil and for soil treated with sugar cane molasses were carried out using standard procedures for testing soil for civil engineering purposes (BS1377:1990). Results showed that molasses reduced the plasticity index of the soil from an average of 39% for untreated soil to an average of 26% for treated soil at molasses content of 8% by weight of dry soil cured for 7 days. Observations of thin sections indicated that soil aggregations formed when 8% molasses content by weight of dry soil was added. However, the aggregations started to disintegrate when molasses content in the mixture exceeded 8%. This indicates that cane molasses reduced plasticity index through aggregation of soil particles and binding of the same by molasses. It was concluded that molasses could reduce the plasticity of expansive clay soil if molasses content in the soil did not exceed 8% by weight of dry soil.

INTRODUCTION

Expansive Clay Soil

An expansive or swelling soil is generally defined as a soil that shows considerable volume changes when its moisture content is altered. Generally, any clay soil that contains clay minerals of the expanding lattice type, for example montmorillonite, could be referred to as expansive or swelling soil (Fitzpatrick, 1986). The bulk density of these soils is unusually high, typically $1.8 Mg/m^3$. Their permeability is very low, either remaining uniform throughout horizon A or decreasing to minimum value in its lowest part (Ndegwa, 1988). The plasticity of this type of soil is quite high as indicated by the plasticity index. Other characteristics of interest in these soils include pH values of neutrality, high base saturation and high cation exchange capacity (CEC) which gives them a high potential for agriculture (Fitzpatrick, 1986). The associated shrink-swell processes create pressures in the soil causing formation of a microtopography called *gilgai* and can result in the cracking of the soil which may extend to structures such as a road founded on the soil.

Cane Molasses

Molasses is a very thick, dark brown, syrupy liquid obtained as a by-product in processing cane sugar. It is also called treacle. It contains resinous and some inorganic constituents that render it unfit for human consumption. This liquid is mildly discomforting and adhesive when it gets into contact with a person's skin. It is slippery when spilt and can be a cause of road accidents if a major spill took place on the road. The study intended to find out whether molasses can alter the plasticity of expansive soil to enable it to be used as a subgrade material for road construction. Due to excessive volume changes, expansive soils cause very serious geotechnical problems in various parts of the world such as distress and damage to structures such as buildings and roads constructed on such soils. Minor rural roads and access tracks that play an important role in rural development become impassable during the wet season in those areas where expansive soil is prevalent. During the dry season dust emissions caused by moving traffic becomes a nuisance to homesteads and institutions. The study was carried out using expansive soil obtained from Kano plains in Kenya. The plains fall within the area where a lot of sugar cane is grown. Most of the sugar manufacturing factories in Kenya are also situated in that region. Cane molasses used in the study was obtained from one of those factories. Currently, roads linking the sugar-growing estates around the sugar factories are in poor condition due to the high cost of construction materials and inadequate construction equipment. The soils found in the region are expansive clays and, since the sugar factories there produce molasses, its use in soil stabilization could reduce the cost of road construction and maintenance in the region. Currently, stabilization of expansive clay soil for engineering purposes is widely carried out using lime. Cement can also be used, but it is not very suitable for this type of soil. The use of molasses for that purpose would provide an alternative cheap technique for stabilizing heavy clay soil. There are also other advantages in its use which include addressing certain environmental issues. The work in this study was limited to

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laboratory tests on soil treated with molasses and on untreated soil.

Soil Plasticity

Atterberg limits are also used in soil characterization. Since the limits vary with soil type, they are widely used in soil classification. For instance, Casagrande (1932) prepared a plasticity chart which is used in classifying clay soil even today. In addition, consistency limits are used as indicators of soil behaviour. A soil with a low plasticity index requires only a small reduction in moisture content to bring about a substantial increase in shear strength. Conversely, a soil with a high plasticity index would not stabilize under load until large moisture content changes have taken place (Carter & Bentley, 1991). This implies that highly plastic soils are less stable and, if they are used in the construction of a road pavement, they may need to be stabilized in order to increase their sheer strength and even their bearing capacity. The Atterberg limits can also give an indication of the type of clay minerals present in a given soil sample. This is deduced from the clay "activity" of the soil. Clay activity of a soil is the ratio of the plasticity index to the percentage of the soil particles finer than 2µm of the same soil as obtained through a sieve analysis. For example, Carter and Bentley (1991) explained that, in pure state, kaolinites have an activity of 0.3–0.5 and sometimes 1.0 illite activity of about 0.9 and montmorillonite activity of greater than 1.5. A high activity is associated with those clay minerals which can absorb large amounts of water within their mineral lattice. The penetration of the clay minerals by water molecules causes an increase in volume of the clay minerals and consequently the swelling of the soil. Thus, activity is a measure of the propensity of clay to swell in the presence of water and can be used to identify expansive soil. Soils which have high liquid limits tend to swell greatly when their water content is increased and shrink greatly when it is reduced (Chen, 1975). It can therefore be deduced that swelling and shrinkage properties are related to the liquid limit and they could be used in identification of expansive clays.

MATERIALS AND METHODS

The reconnaissance of the study area was conducted in order to identify the specific locations from which soil could be taken. Reconnaissance also enabled: physical observation of the *in situ* soil; assessment of general geological features of the area; landscape observations; observations of the area's vegetation and general drainage.

Soil Sampling

The sampling site was selectively chosen so that it conformed to vegetation and land topography which are associated with existence of expansive soil. The trial pits from which the soil samples were obtained were randomly spread over a large area. They were excavated manually using picks and spades to a depth not exceeding one metre because it was hard to excavate manually beyond that depth and because the soil type frequently changed beyond that depth as well. The logging of the trial pits was carried out before soil sampling took place. Logging involved description of the soil profile as observed on the face of the pit.

Since the swelling potential of expansive soil reduces drastically from one metre depth onwards, the sampling depth range did not reach the one metre mark due to this and other reasons mentioned above. The trial pits were excavated to an average depth of 0.65m. Sampling depth was restricted to between 0.20m and 0.50m. The soil from the surface, to a depth of 0.20m, was excluded from the sample because it is not normally used during road construction. Furthermore, it contained a lot of vegetable matter and therefore unsuitable for this research. The sampling depth was restricted to the 0.50m mark on average because, beyond that depth, the soil material gradually changed from clay soil to clay mixed with gravelly material. In addition, the depth range from which soil samples were taken was appropriate to enable capturing the soil material which had high potential for expansion or shrinkage when its moisture content changed. During sampling the soil was cut from the trial pit face starting at 0.20m and ending at 0.50m depth in form of slices which were well distributed over the trial pit face. It was then properly mixed while ensuring no deleterious material was included and then put into small gunny bags. Some samples were put in plastic bags in order to preserve the moisture content of the soil. The samples were then delivered to the laboratory for further preparations according to the required tests. The soil preparations were carried out according to BS 1377, Part 1: 1990 or BS 1924: 1990 procedures depending on the type of laboratory test to be carried out.

Laboratory Tests

The laboratory tests involved included tests on plain soil and on soil stabilized with molasses.

Soil Testing Methods

Soil testing is usually based on the premise that the behaviour of the soil masses under imposed conditions could be predicted if certain soil properties were measured. The soil tests in this study were carried out on soil samples that were truly representative of the soil at the site. The test conditions were such that they closely simulated *in situ* subgrade conditions as well.

Quick Assessment Tests

The rapid procedures were carried out both in the field and in the laboratory to give a personal judgment of the soil based on its appearance and feel to the touch when rubbed between fingers. The assessment generally indicated whether the soil was plastic or non-plastic. Before the quick assessment was carried out, larger particles were first removed. The largest soil particles that were allowed in the soil specimen were about 0.06mm. The soil, at its natural moisture content, was remoulded together by hand to assess cohesion and subsequently assist in assessing plasticity. Cohesion of the soil was usually indicated if the soil could be remoulded into a relatively firm mass. Plasticity in turn could be indicated if the soil was deformed without loss of cohesion. If cohesion and plasticity were pronounced, the fines were said to be plastic. In contrast, if cohesion and plasticity were absent or weakly indicated, the fines would be essentially non-plastic. The quick assessment of plasticity of fines was effected through dry strength, toughness and dilatancy tests. The tests were carried out as per BS 5930:1981.

Visual Examination

Visual examination of the soil *in situ* was also carried out in order to check for any significant proportion of dispersed vegetable matter in it. The vegetable matter that was checked included plant roots up to a depth of about 150mm from the ground surface. The colour and the general texture of the soil, including the presence of any distinctive odour, were checked.

Physical and Chemical Soil Tests

The tests in this category were carried out as stipulated in standard procedures such as BS 1377:1990 or BS 9124:1990. The tests which were meant for the identification and clarification of the soil included: pH value of the soil, organic matter content, cation exchange capacity (CEC), elemental oxide composition, particle size distribution, texture, specific gravity, Atterberg limits on untreated and on treated soils and free swell. Thin sections from molasses-soil mixture were prepared to enable observance under a petro-graphic microscope of soil particles before and after mixing with cane molasses.

2. The mixture was then put in a cylindrical mould (100 mm diameter and 63 mm long).
3. A cylindrical specimen was then prepared by impact compaction with a special hammer of 4.5kg falling freely through a height of 450mm and giving each face of the specimen 75 blows.
4. After each face was given 75 blows, the specimen was then extruded from mould and wrapped in plastic bag to prevent change in moisture content.
5. After dissipation of pore pressure set up during compaction, a slice was cut from the cylindrical specimen then slabbed and trimmed down to fit the slide.
6. In order to achieve a flat reference for subsequent bonding and to obtain uniform thickness over the slice area, one face of slice was lapped flat.
7. After lapping, the standard procedure used in making thin sections of rocks was followed.

RESULTS

Quick Assessment Results

- It was difficult to crumble the dried soil pat or even break it between fingers. The dry strength was relatively high.

Table 1: Results on Physical and Chemical Characteristics of the Soil Understudy

Specimen designation	TP1 (3)	TP 3 (3)	TP 5 (3)	TP6 (3)	TP8 (3)	TP9 (3)	TP10 (3)
Sampling depth (cm)	20 - 50	20 - 50	20 - 50	20 - 40	20 - 40	20 - 50	20 - 50
Soil pH-H_2O (1:2.5)	6.7	6.3	6.8	7.3	7.2	7.7	7.5
Sand %	18.0	18.0	18.0	16.0	12.0	18.0	18.0
Silt %	16.0	20.0	16.0	16.0	26.0	14.0	16.0
Clay %	66.0	62.0	66.0	68.0	62.0	68.0	66.0
Texture class	C	C	C	C	C	C	C
EC mS/cm	0.7	0.4	0.5	0.5	0.6	0.7	0.9
ECe mS/cm	3.5	2.0	2.5	2.5	3.0	3.5	4.5
C %	1.2	1.3	1.4	1.0	1.3	1.3	0.9
C E C (me/100g)	38.0	17.7	19.4	24.6	26.1	36.3	24.3
Exch. Calcium (me/100g)	28.0	26.4	20.3	31.0	27.2	25.5	23.7
Exch. Magnesium (me/100g)	3.3	3.3	2.4	3.2	2.3	2.7	2.7
Exch. Potassium (me/100g)	1.6	1.5	1.0	1.5	2.0	1.5	1.2
Exch. Sodium (me/100g)	4.0	3.0	3.0	5.0	5.0	4.0	4.0
Sum of bases (me/100g)	36.9	34.2	26.7	40.7	36.5	33.5	31.6
Base Saturation %	97.0	100.0+	100.0+	100.0+	100.0+	93.0	100.0+

Table 2: Atterberg Limits on Neat Soil under Study

Soil Specimen	LL (3)	PL (3)	PI (3)	LS (3)	% Passing 425µm Sieve (3)	PM (3)	Plasticity Index	Plasticity Description (Venkatramaiah, 1995)
TP 1	78	42	36	18	99	3550	0	Non-plastic
TP 2	73	31	42	21	99	4158	1-5	Slight
TP 3	73	35	38	19	98	3724	5 – 10	Low
TP 4	75	39	36	18	94	3384	10 – 20	Medium
TP 5	87	47	40	18	98	3920	20 – 40	High
TP 6	69	31	38	19	98	3724	> 40	Very high
TP 7	66	30	36	18	99	3564		
TP 8	78	38	40	20	99	3960		
TP 10	82	41	41	20	98	4018		
Average	76	37	39	19	98	3822		

Key: LL – Liquid Limit; PL – Plastic Limit; PI – Plasticity Index; LS – Linear Shrinkage; PM – Plasticity Modulus

Preparation of Thin Section from Soil-Molasses mixture

1. Expansive clay soil was thoroughly mixed with required amount of molasses until it was homogeneous.

- Regarding the toughness test, the threads formed were fairly stiff and tough.
- When the soil pat was struck between the palms of the hand it splashed mud and when squeezed mud flowed out between fingers.

- No distinctive odour from the soil was detected and the colour of the soil from various trial pits varied from dark to grey and the soil was also fine grained.

Physical and Chemical Soil Tests' Results

The pH Test Results

The pH values indicated the soil was neutral implying that it was vertic. Vertic soils contain expanding clay mineral, especially smectites (Fitzpatrick, 1986). But when the soil was treated with molasses, the pH value changed and the soil became slightly acidic. This means that the addition of molasses resulted in a cation exchange reaction.

Test Results on Organic Matter Content

The organic matter content was much below the maximum recommended by Ministry of Transport and Communications (Kenya) (1987) which is 3%. The results indicated no adverse effect on compaction of neat soil or and on soil treatment with molasses could occur if the material was used in road construction.

Test Results on: Cation Exchange Capacity; Salinity; Exchangeable bases; Base saturation and Textural classification

The results are shown in Table 1. These results indicate that the soil used was heavy clay since its clay content was > 60% and the cation exchange capacity was high typical of heavy clay soil.

Elemental Oxides' Analysis of the Soil

Results showed that the soil was montmorillonitic clay. This type of soil is found in arid and semi-arid areas and it is expansive. Particle size distribution indicated the soil was fine grained which is typical of clay soil.

Specific Gravity Test Results

The specific gravity results fell within the range for clay soil.

Atterberg Limits' Results for Untreated Soil

The results are shown in Table 2.The results show that plasticity for neat soil was high. Thus the soil could undergo large volumetric changes if its moisture content changed.

Test Results on Free Swell

The results showed that the swell class for tested soil was high. This indicated the soil could undergo large volumetric changes if its moisture content changed.

Plasticity Test Results on Soil Treated with Molasses

Results are graphically represented in Figure 1 for specimens TP3, TP4, TP5, TP7, TP8 and TP10 respectively. Figure 1 show the relationship between molasses content and plasticity index for soil specimens treated with molasses and cured for 7 days.

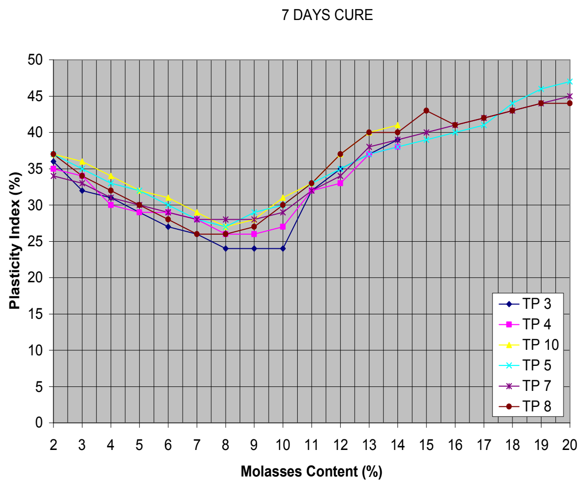

Figure 1: Plasticity Index versus Molasses Content
(7-day cure; all specimens)

Results of Thin Sections of Molasses Moulded Clay Soil Samples

Plain Soil: Grain Size < 20mm

Under the petrographic microscope, the following were the observed characteristic features:

- The non-clay particles (i.e. quartz and opaque ores) in the plain soil (i.e. non-moulded clays) samples were evenly and homogenously distributed without any bias of segregation. The non-moulded clay samples (i.e. the plain soil samples) appeared to have an evenly and homogeneously distributed particle sizes with low percentage/degree of nodular segregation as shown in plate 1.

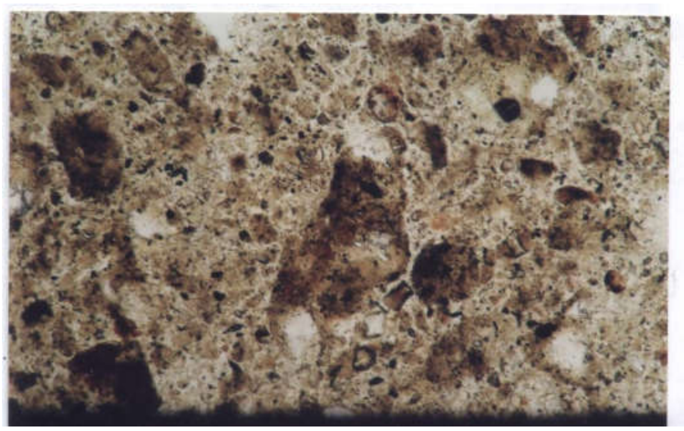

Plate 1: Plain soil (soil grain size < 425µm) magnified 100 times

Soil Mixed with 8% Molasses: Grain Size <20mm

- Under the microscope, the cementing matrix (i.e. molasses) appeared as a pale brown non-crystalline amorphous medium.
- Nodules of the moulded clay soil particles were portrayed as dark coloured with sub-angular to sub-rounded granular outlines.
- Particles of clay soil stabilized with molasses appeared agglomerated into larger sizes than those of the plain soil.

- Some moulded clay soil samples did not mix well with the cementing medium (molasses). The patches that were observed appeared well-sorted and cement-free fine grained clay particles with relatively good porosity stood out. This could be attributed to inadequate mixing of the molasses-soil mixture.

Soil Mixed with 12% Molasses: Grain Size < 20mm

Under the petrographic microscope, the following were the observed characteristic features:

- The cementing matrix (i.e. molasses) appeared light to dark brown in colour.
- The non-clay particles (e.g. quartz fragments and opaque ores) appeared to have a low degree of adherence with the cementing matrix (i.e. molasses) and commonly segregated themselves into the pores of the moulded clay samples.
- Moulded clay with 12% molasses appeared to have a higher degree of inter-granular penetration within the individual clay nodules as compared with the 8% moulded clay. This textural difference was observed in the style and manner in which the differently concentrated cementing matrix (molasses) interacts with the clay particles. This was considered as a key factor in explaining the changes in plasticity of molasses stabilized clay soil. It was also a factor to consider when dealing with the compaction, and strength properties of clays stabilized with cane molasses.

Soil Mixed with 8% Molasses; Grain Size < 425μm

Under the petrographic microscope, the following were the observed textural features:

- The non-clay particles (e.g. quartz fragments and opaque ores) once again appeared to have a low degree of adherence with the cementing matrix and segregated themselves into the empty pores.
- Sub-angular to sub-round nodular clay particles which were bigger than those of plain soil of same grain size were observed as shown in Plate 2.
- The same plate also illustrated that numbers of pores for the moulded clay of <425μm in diameter appeared to be relatively fewer compared with those of <20mm in grain size

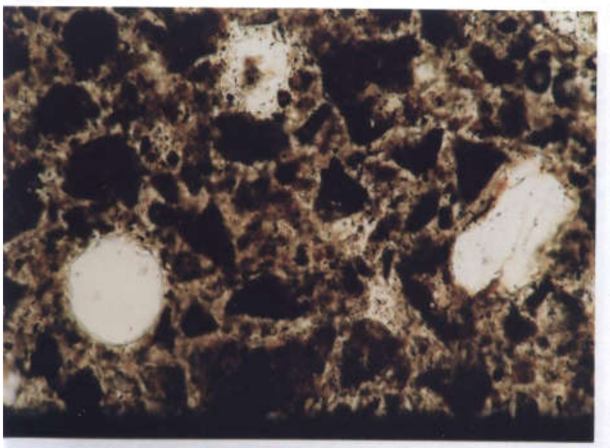

Plate 2: Soil–molasses mixture (molasses content 8%, soil grain size < 425μm) magnified 100 times

Soil Mixed with 12% Molasses: Grain Size < 425μm

Under the petrographic microscope, the following were the observed characteristic features:

- The cementing medium appeared to have wholly engulfed and interpenetrated the individual grains of the clay nodules. There was comparatively less aggregation of the nodular clay particles.
- The non-clay particles followed similar trend of segregation to the pore spaces.
- Texturally the aggregated clay particles were comparable with those of plain soil having the same grain size.

Segregation of Non-clay particles in Molasses Stabilized Clay Soil

- The non-clay particles (e.g., quartz fragments and opaque ores) appeared to have a low degree of adherence with the cementing matrix (i.e. molasses) and commonly segregated themselves. This phenomenon was observed in all soil samples irrespective of the grain size and the molasses content in the soil.
- It was further observed that there was a biased form of segregation of these grains into the pores (i.e. empty spaces) of the samples.

Particle Size Increase Mechanism

- Addition of cane molasses to expansive clay soil caused cation exchange that led to reduction of double layer thickness.
- Reduction in double layer thickness caused flocculation of clay particles and eventually aggregation.
- The cation that caused flocculation reduced also the amount of adsorbed water in clay and consequently caused reduction of water content of liquid limit of clay (Haddinott & Lamb, 1990). But water content of plastic limit and shrinkage limit increased respectively. Reduction in liquid limit and increase in plastic limit resulted in reduction of plasticity index.
- Aggregation increased effective gain sizes as illustrated by photographs taken under spectrographic microscope. Aggregation/ aggromeration changed textural condition of clay soil and reduced the specific surface of soil particles. This agrees with Osinubi (1995).
- Consequently liquid limit was reduced, plastic limit increased and plasticity index reduced.

Adhesivity Mechanism

- Electrochemical attraction between aggregated soil particles was enhanced by molasses adhesivity which bound the particles together. Adhesivity properties of molasses were derived from Hydrogen bonds attributed to Hydroxyl group found in sucrose of molasses.
- The clay soil particles were then held together by molasses and they formed larger particles than clay size grains which caused reduction in clay content of

soil and ultimately decreased liquid limit due to lower specific surface, and increased plastic limit.

- Molasses increase in clay soil beyond a certain limit caused the soil aggregate to disintegrate. Thereby leading to decrease in size of individual aggregates and finally the soil reverted to its fine condition. This was demonstrated by photographs taken under petographic microscope.
- As molasses content was increased in the soil, in the limit soil mass flowed under its own weight.

DISCUSSION

Considering each specimen's PI results on one day's cure it was observed that:

- PI for TP3 reduced from 38% at 0% molasses content to 24% at 8% molasses content;
- PI for TP4 reduced from 36% at 0% molasses content to 26% at 8% molasses content;
- PI for TP5 reduced from 40% at 0% molasses content to 28% at 8% molasses content;
- PI for TP7 reduced from 36% at 0% molasses content to 28% at 8% molasses content;
- PI for TP8 reduced from 40% at 0% molasses content to 26% at 8% molasses content, and
- PI for TP10 reduced from 41% at 0% molasses content to 28% at 8% molasses content.

PI for specimens that underwent 7 days cure changed as follows:

- PI for TP3 reduced from 38% at 0% molasses content to 24% at 8% molasses content;
- PI for TP4 reduced from 36% at 0% molasses content to 26% at 8% molasses content;
- PI for TP5 reduced from 40% at 0% molasses content to 27% at 8 % molasses content;
- PI for TP7 reduced from 36% at 0% molasses content to 28% at 8% molasses content;
- PI for TP8 reduced from 40% at 0% molasses content to 26% at 8% molasses content, and
- PI for TP10 reduced from 41% at 0% molasses content to 27% at 8% molasses content.

Considering each specimen's PI results on 28 days' cure, it was observed that:

- PI for TP3 dropped from 38% at 0% molasses content to 24% at 8% molasses content;
- PI for TP4 dropped from 36% at 0% molasses content to 26% at 8% molasses content;
- PI for TP5 dropped from 40% at 0% molasses content to 26% at 8% molasses content;
- PI for TP7 dropped from 36% at 0% molasses content to 26% at 8% molasses content;
- PI for TP8 dropped from 40% at 0% molasses content to 25% at 8% molasses content, and
- PI for TP10 reduced from 41% at 0% molasses content to 26% at 8% molasses content.

These changes show that there is no significant difference in PI between durations of cure applied in the study. The increase in PI for TP5 after 7 days' and 28 days' cure could be attributed to atmospheric moisture absorption by tested soil before it was put in the oven for determination of moisture. The same can be said of other specimens, which showed increase in PI on duration increase.

Conclusion

It was concluded from the study results that cane molasses can reduce the plasticity index of expansive clay if not more than 8% of it is added to the soil.

RECOMMENDATIONS

From the foregoing study and discussion, the following recommendations were made:

1. Plasticity characteristics of molasses stabilized soil need to be evaluated in long-term field trials.
2. Further study to establish duration required for completion of flocculation and aggregation process of soil particles on addition of molasses is recommended.

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